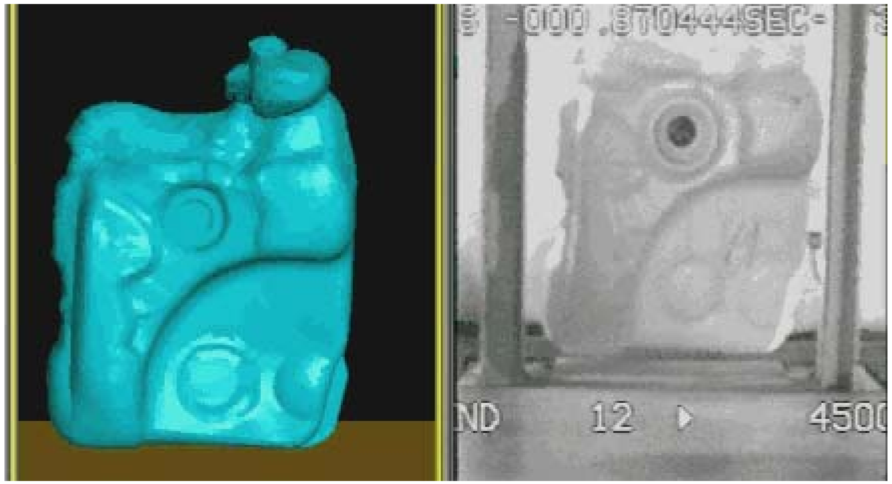
Einfluss der Materialmodellierung von thermoplastischen Kunststoffen auf Ergebnisse von numerischen Falltests



andreas.wuest@basf.com

Contents

BASF The Chemical Company

- Motivation
  - Was ist das besondere an einer Falltestsimulation?
  - Erfahrungen aus der Praxis → Fallstricke
- Materialverhalten von Kunststoffen – BASF ULTRASIM™
  - Faserorientierung
  - Dehnratenabhängigkeit
  - Asymmetrie in Zug-Druck
  - Anisotropie
  - Versagensmodellierung
- Ausgewählte Beispiele
- Diskussion

BASF and CAE?
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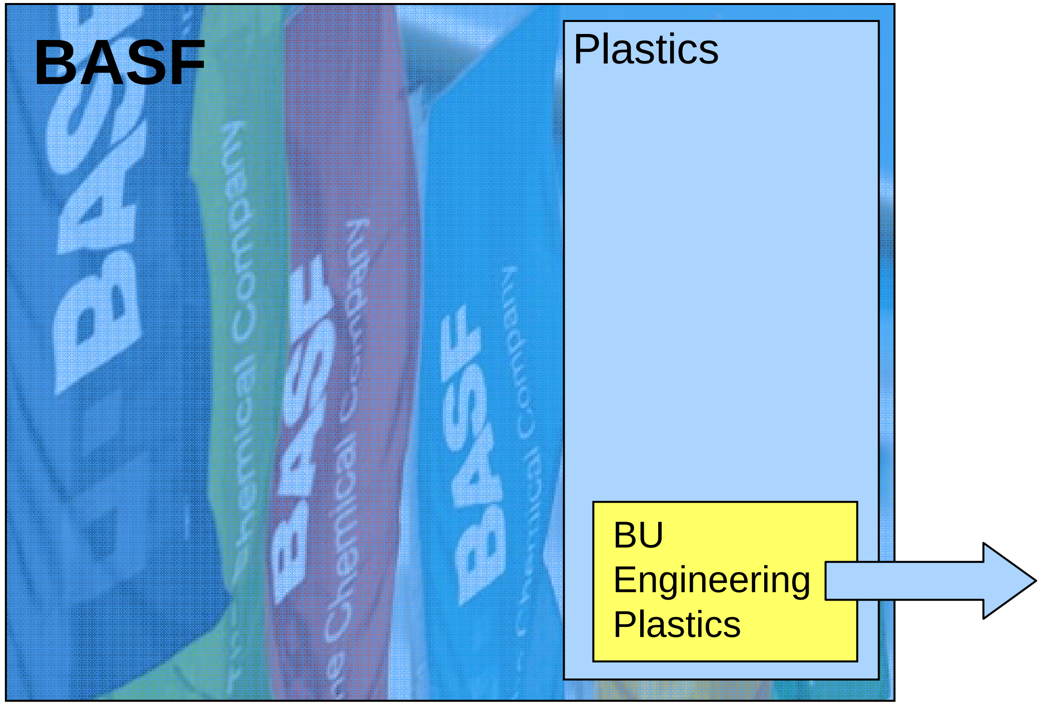

Thermoplastic Materials

+ Customer Support:

- Application Development Services
    - Material Modelling
    - Mechanical Analyses
    - Filling Analyses

CAE

Motivation

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- Was ist das besondere an einer Falltestsimulation?
  - Kinematisch anspruchsvoll
    - Kontaktabbildung, Postprocessing
  - Simplifikationen sind erschwert!
    - Verbindungsmodellierung (Schrauben, Kleben, …)
  - Abbildung von Material und Versagen ist eine zentrale Aufgabe
    - Nichtlinearitäten, Anisotropie, …
  - Lokale Größen dominieren
    - Netzfeinheit und Netzgüte
      - Resultat Absenkung → Steifigkeit → globale Größe
      - Resultat Versagen → Failure-Wert → lokale Größe

Vereinfachung Schraube

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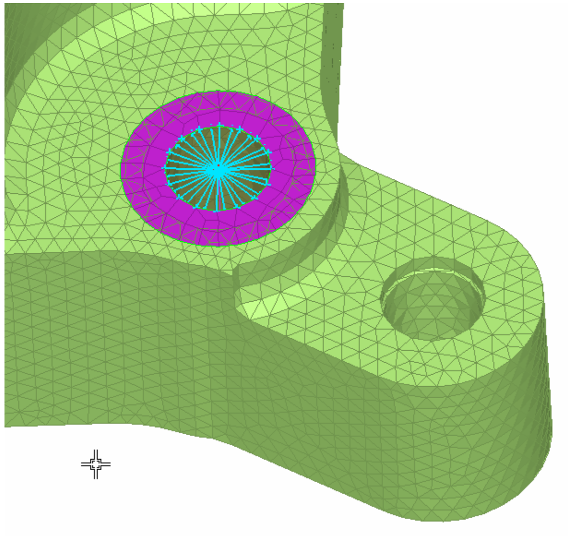

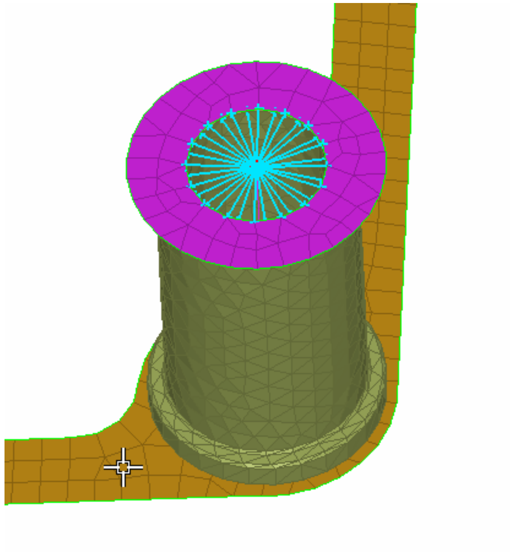

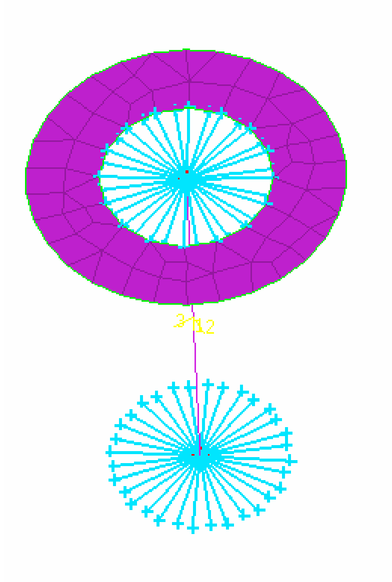

Schraube ist geometrisch nicht vorhanden!

Probleme:
- Krafteinleitung
- was passiert nach dem Versagen?

Vereinfachung Schraube

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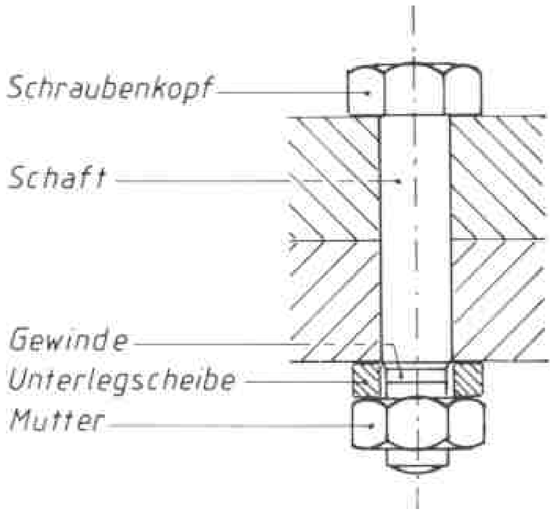
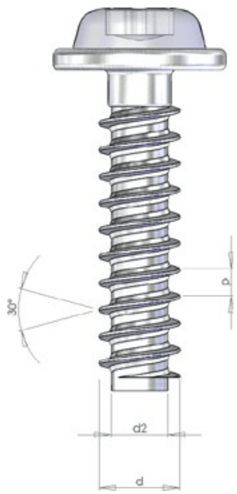
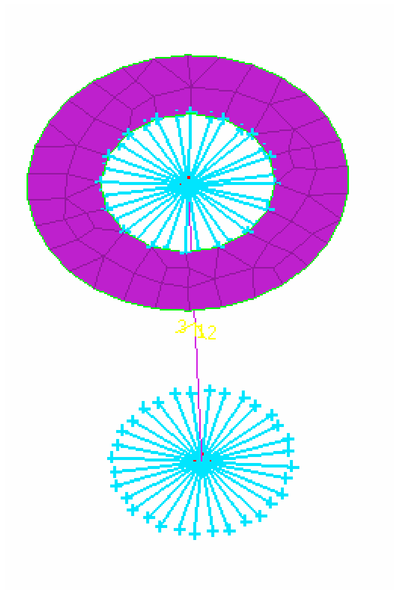
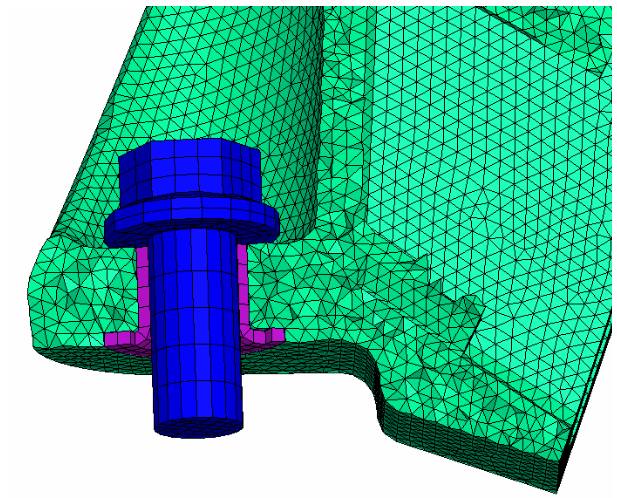






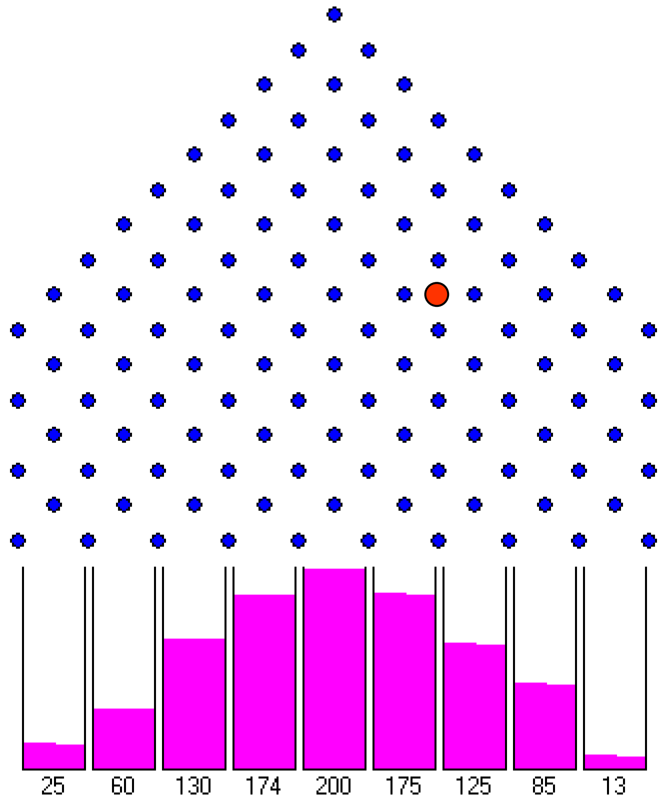
vereinfacht



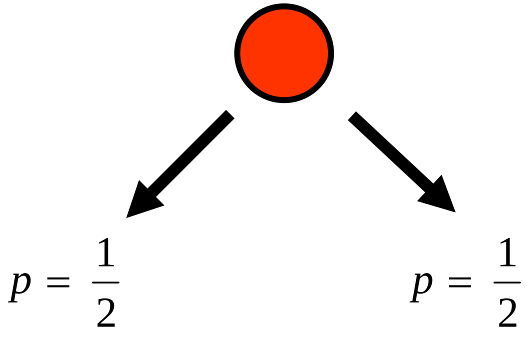
geometrisch korrekt

Gefahr: Bifurkation durch nichtphysikalisches Verhalten
Lösung schlägt einen anderen Pfad ein!

Galton Brett
Pfadabhängigkeit



Bifurkation (Gabelung)



Netzeinfluss - Netzgüte

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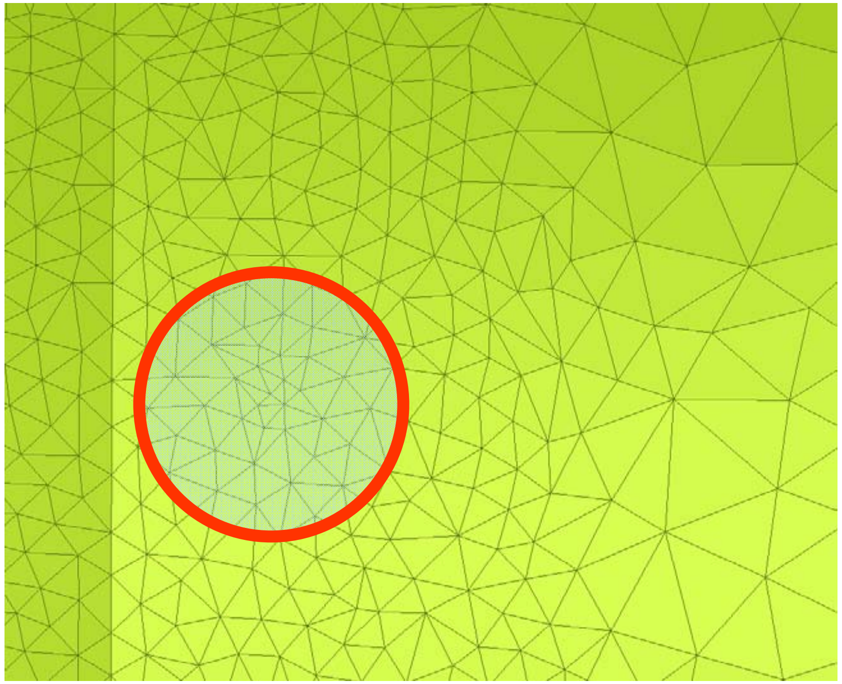
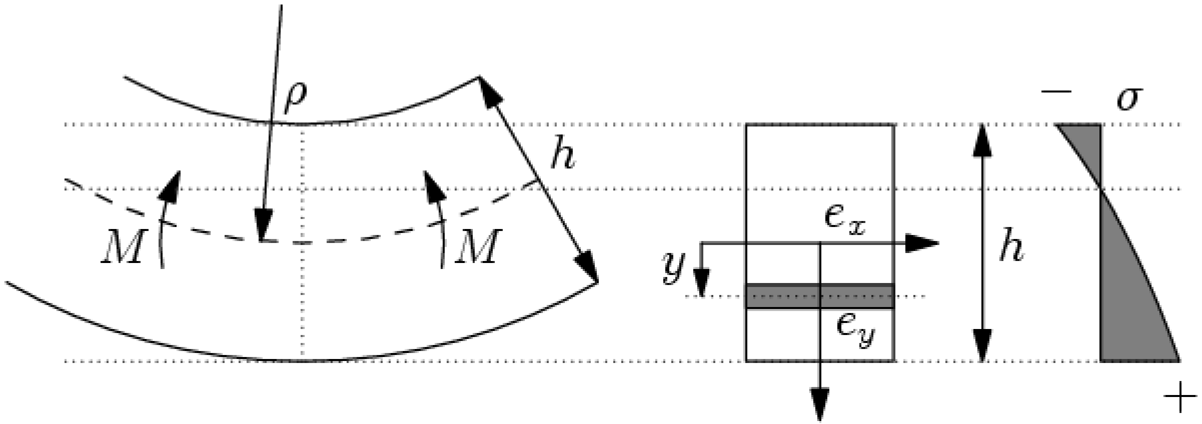


Resultat Absenkung → Steifigkeit → globale Größe
Resultat Versagen → Failure-Wert → lokale Größe

- Numerischer Einfluss schlechter Elemente kann dominieren

- Solidelemente → Netzchecks im Inneren beachten!

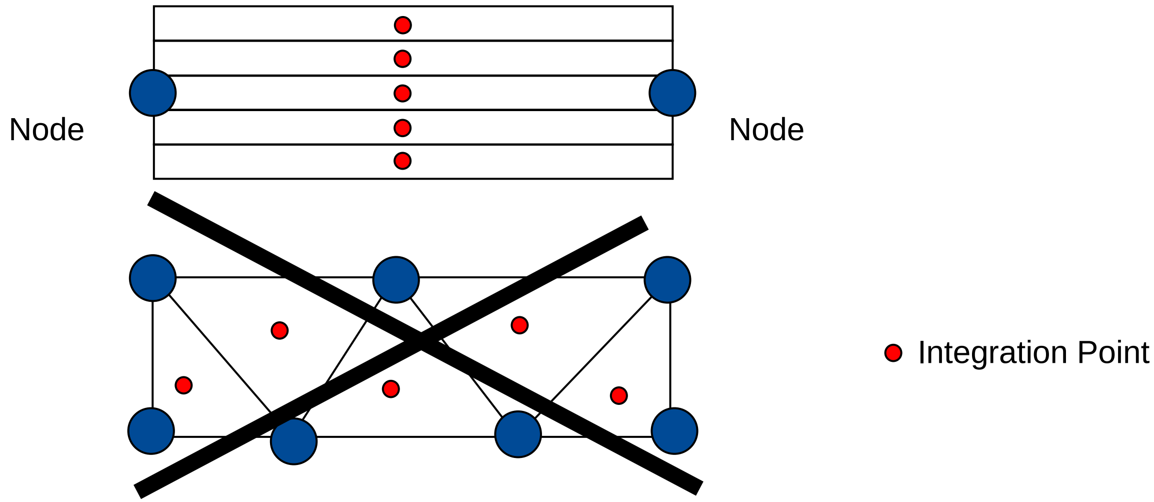
Netzeinfluss - Netzfeinheit



Schale unter Biegung

Shell-Element

Solid-Element



Integrative Simulation ULTRASIM™

for short fiber reinforced thermoplastics

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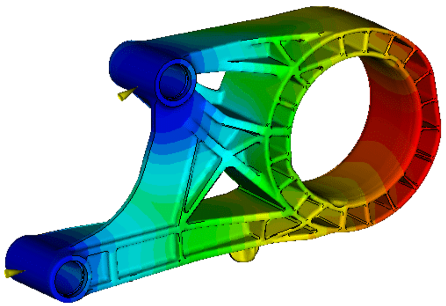
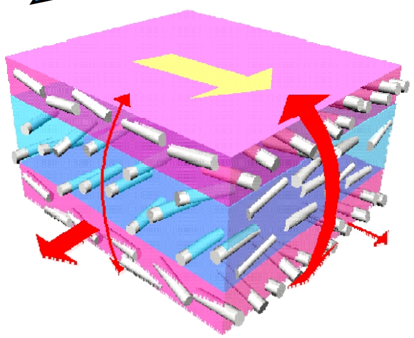
Process

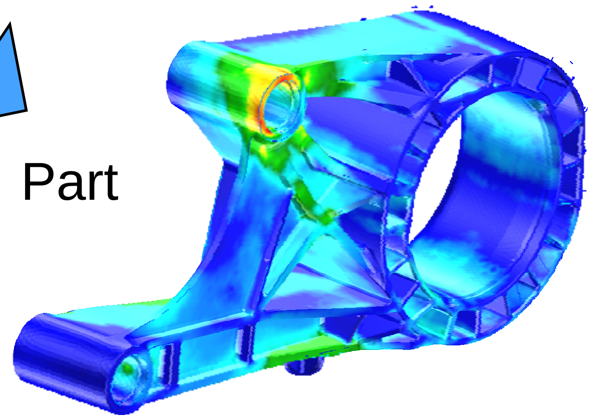


Measurement

Material



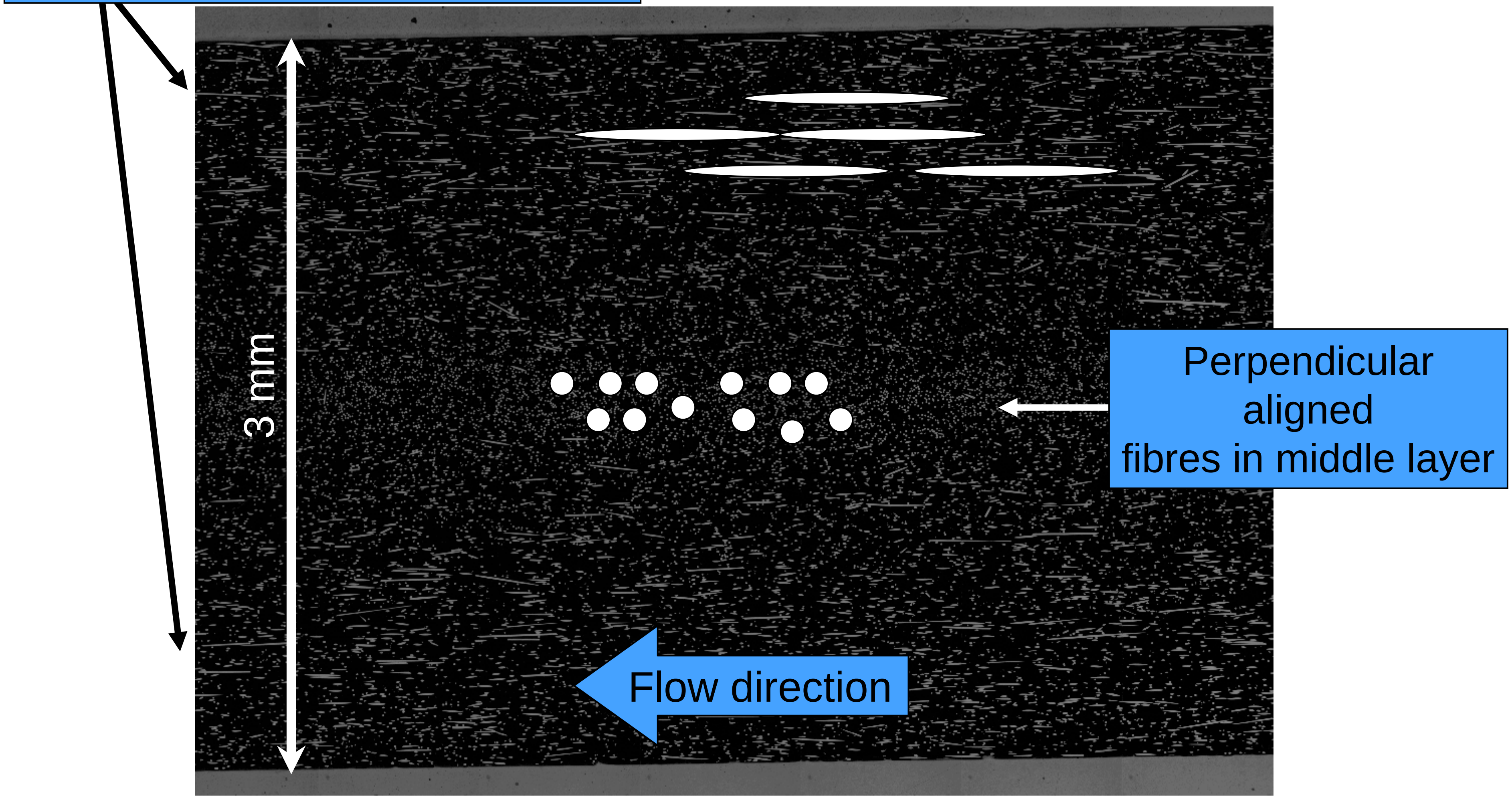
Part



- Anisotropic
- Nonlinear
- Strain-rate sensitive
- Tensile-compression asymmetric
- Failure modelling
- Temperature dependent

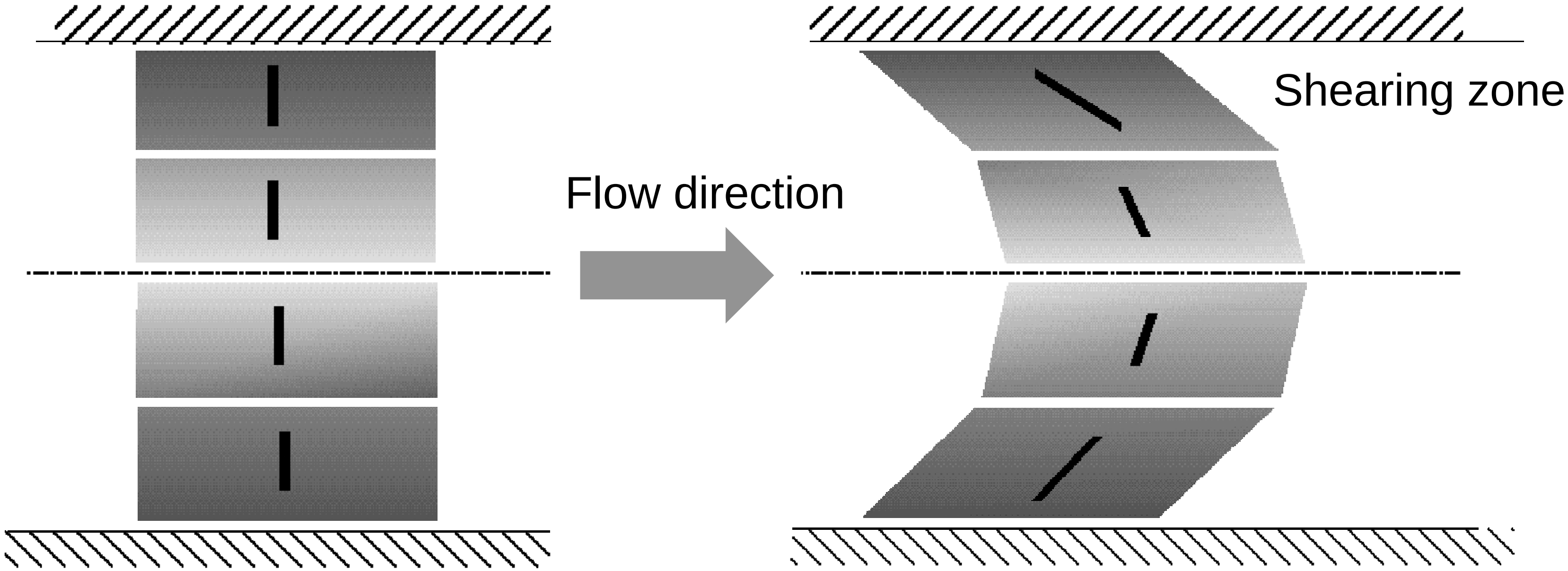
Cross section PA GF30

Flow aligned fibres near tool walls



Evolution of Fiber Orientation in Mould Filling Process

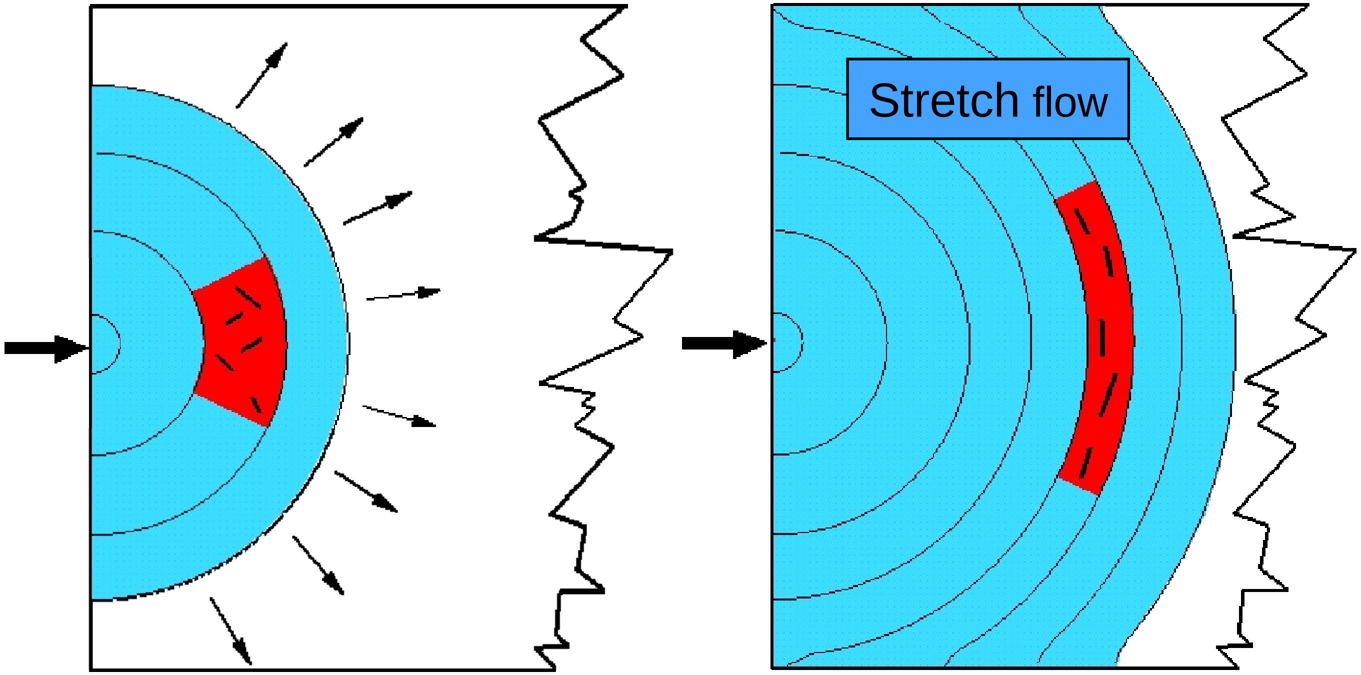
Cross sectional view



Due to shearing in the boundary layers
the fibers are oriented in flow direction

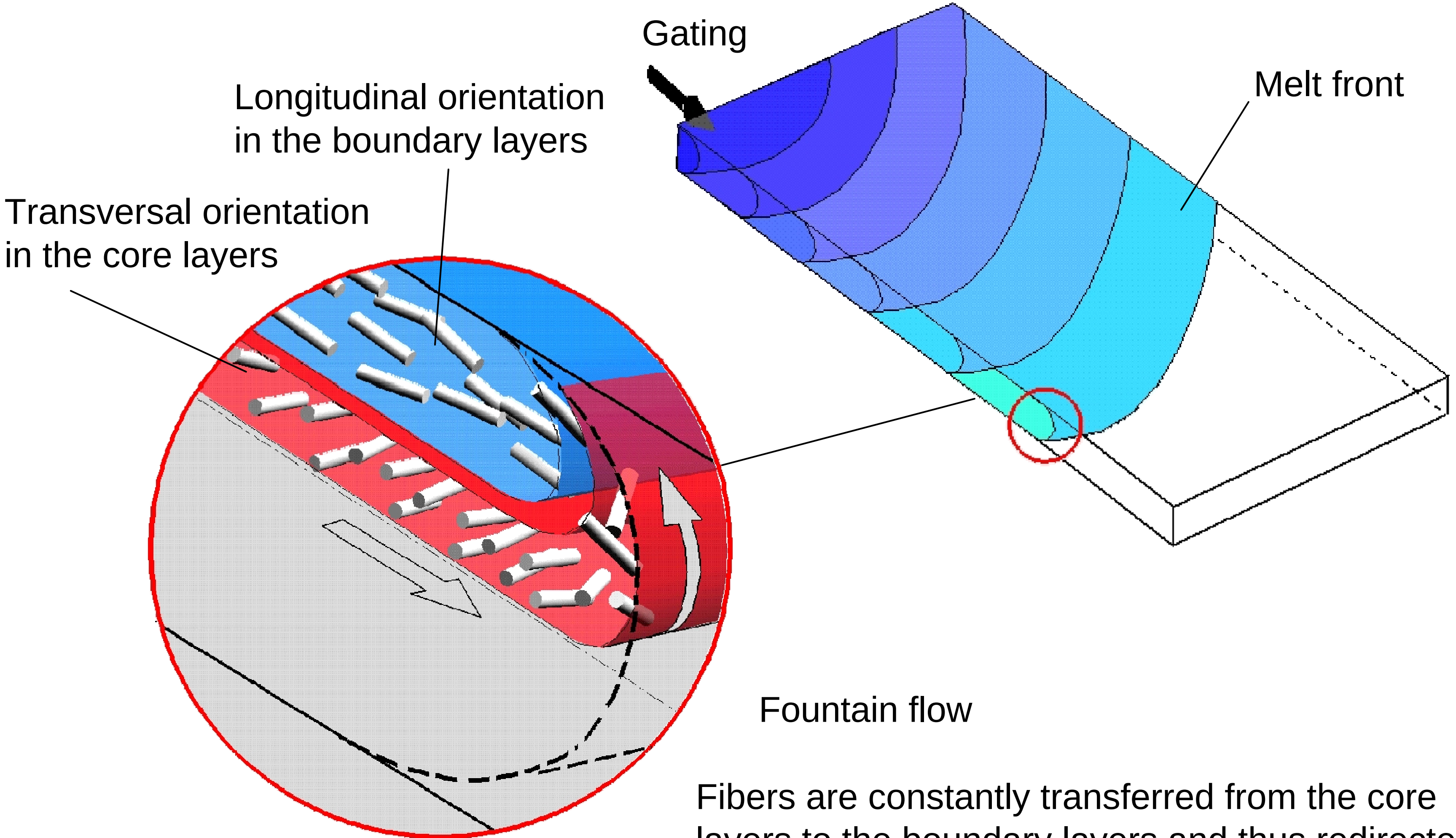
Evolution of Fiber Orientation in Mould Filling Process

Upper view



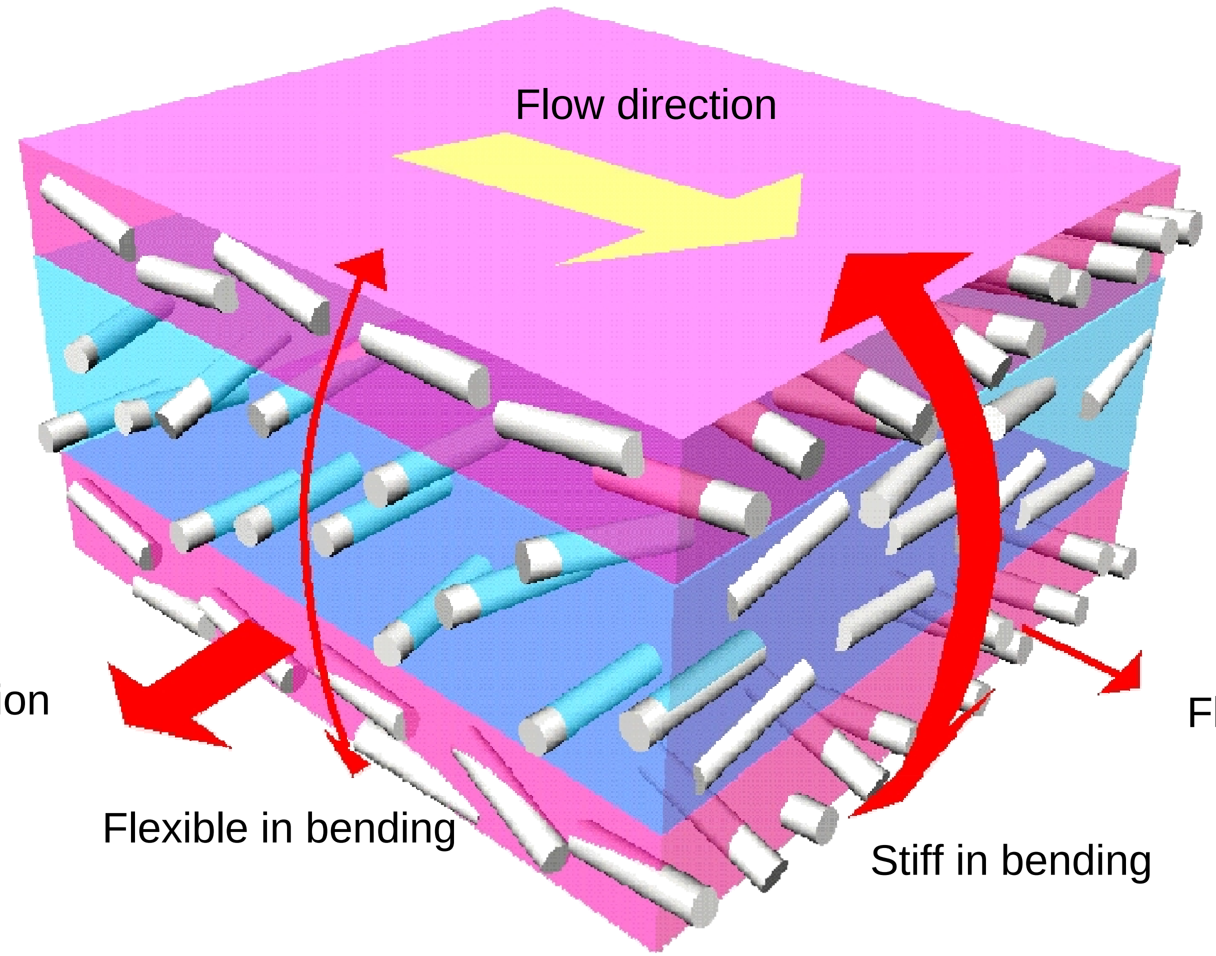
Fibers are being oriented in stretching direction

Evolution of Fiber Orientation in Mould Filling Process



Fibers are constantly transferred from the core layers to the boundary layers and thus redirected

Mechanical behaviour of anisotropic layered shells



Motivation for Anisotropic Material Modelling

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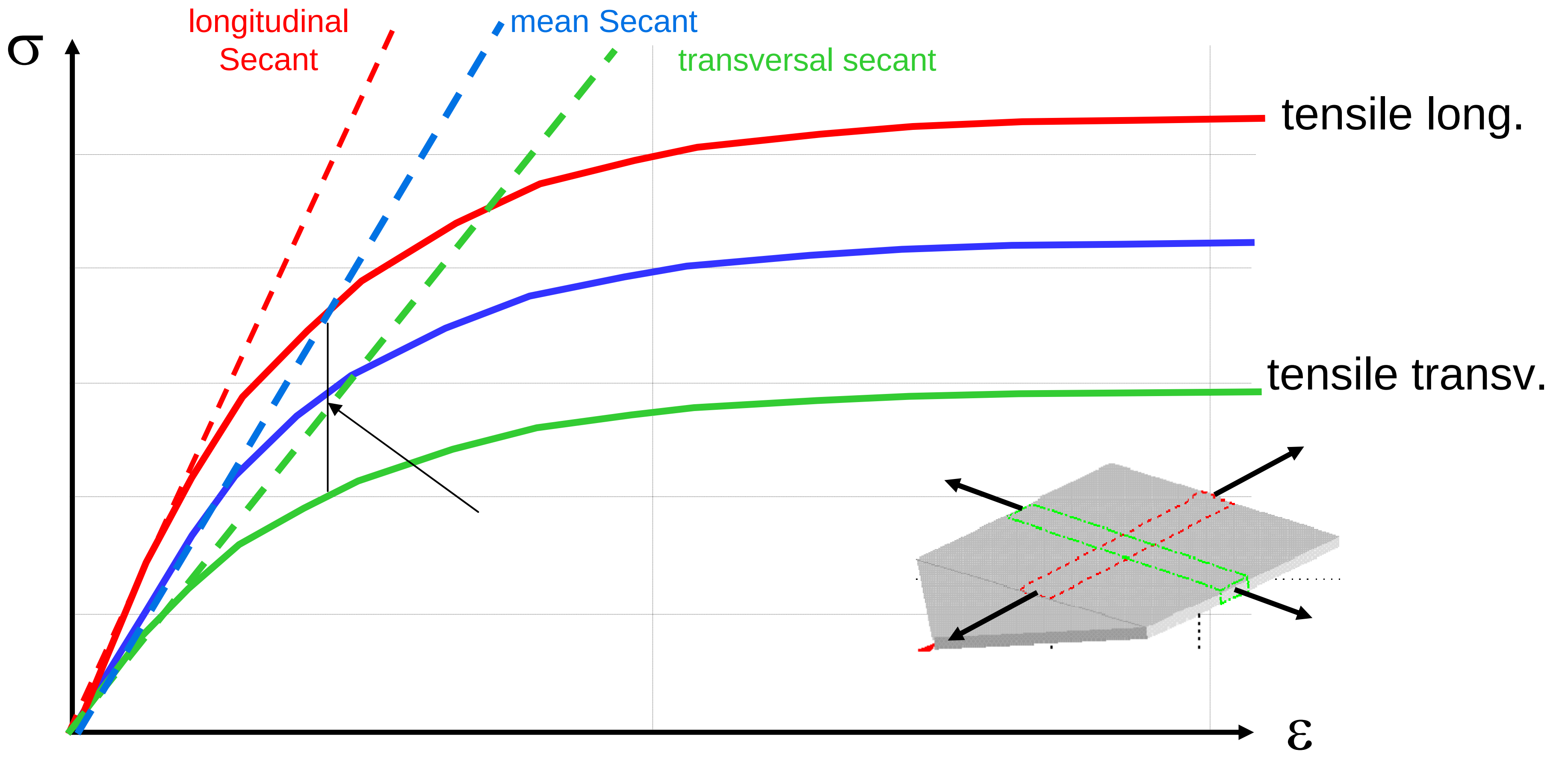
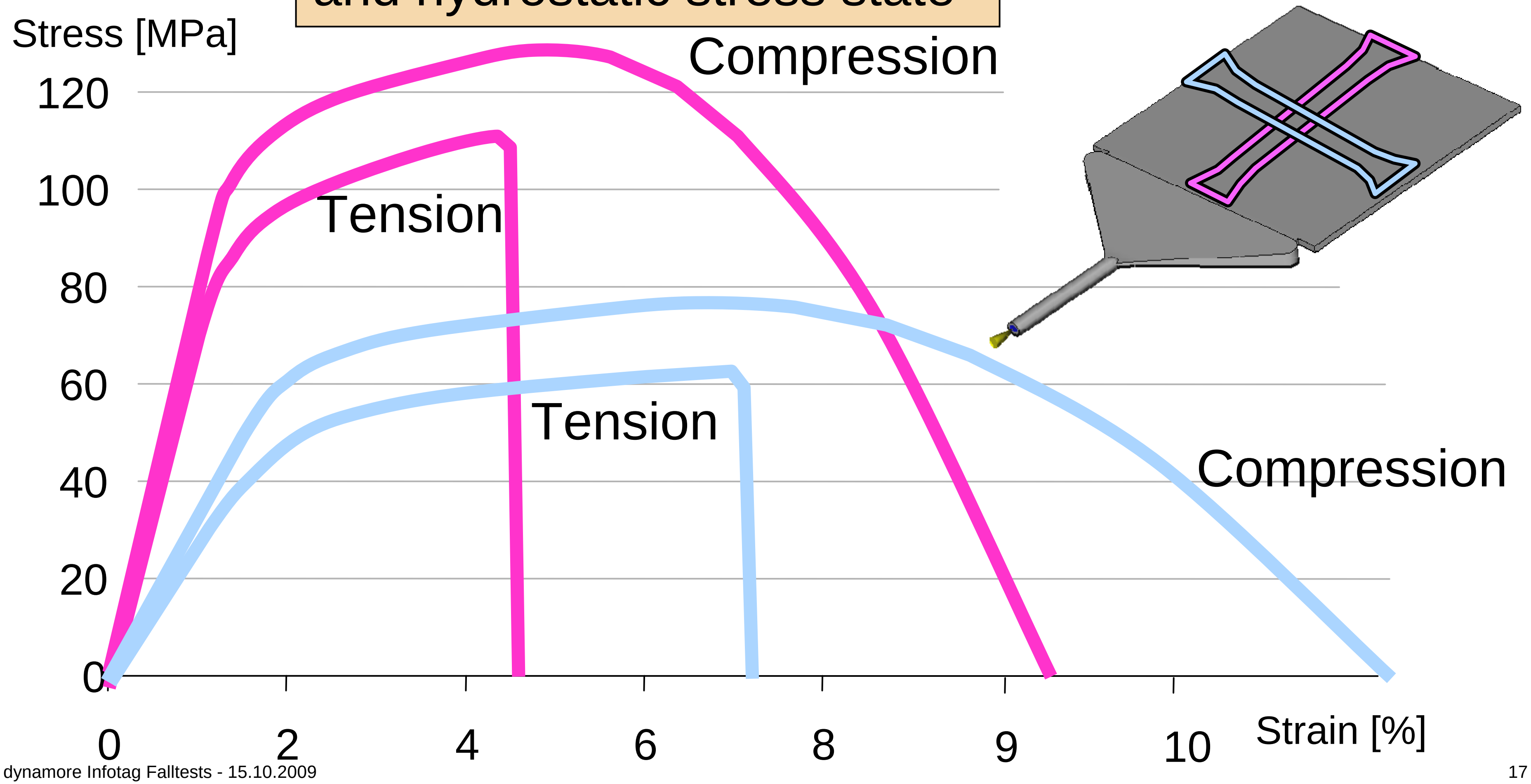
Anisotropy due to fiber orientation



Fiber reinforced Polymer, Stress-Strain

influence: fiber orientation and hydrostatic stress state

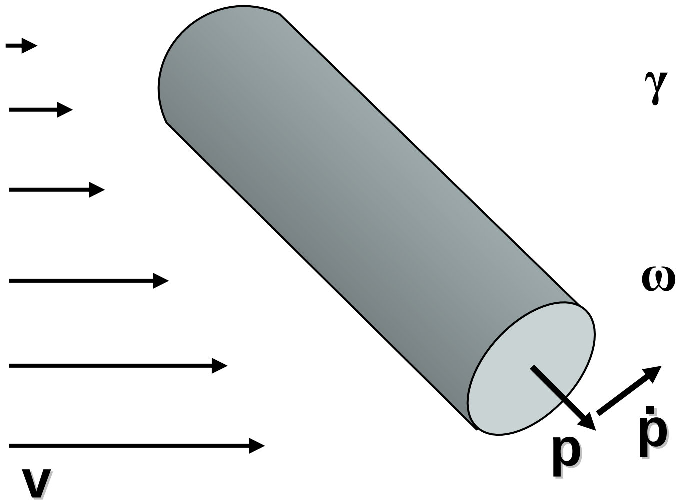
Injection moulded plate



Evolution of fiber orientation

Jefferey 1922

$$\dot{\mathbf{p}} = -\boldsymbol{\omega} \cdot \mathbf{p} + \lambda\left(\boldsymbol{\gamma} \cdot \mathbf{p} - \left(\mathbf{p} \cdot \boldsymbol{\gamma} \cdot \mathbf{p}\right)\mathbf{p}\right) - \frac{D_r}{\psi}\frac{\partial \psi}{\partial \mathbf{p}} \quad ; \quad \lambda = \frac{(l/\mathrm{d})^2 - 1}{(l/\mathrm{d})^2 + 1}$$



$$\boldsymbol{\gamma} = sym\left[\frac{\partial \mathbf{v}}{\partial \mathbf{x}}\right]$$ Rate of deformation

$$\boldsymbol{\omega} = skew\left[\frac{\partial \mathbf{v}}{\partial \mathbf{x}}\right]$$ Vorticity

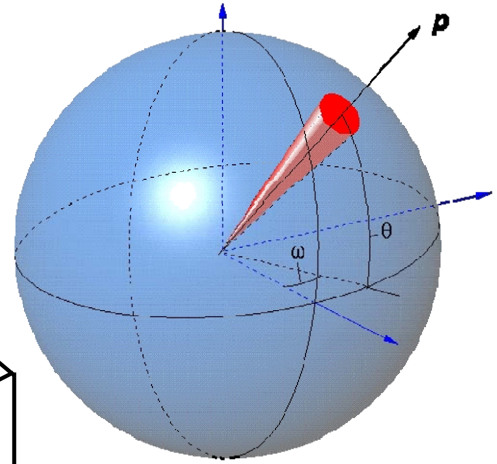
Orientation distribution function

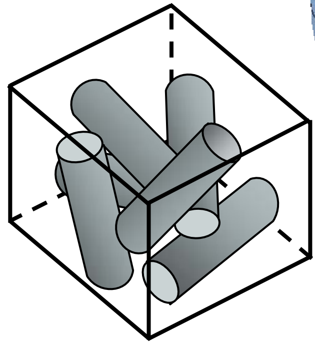
Orientation tensors

$$\mathbf{a} = \int_{\omega} \mathbf{p} \otimes \mathbf{p}\, \psi(\mathbf{p})\, d\omega$$

$$\mathbf{a}^4 = \int_{\omega} \mathbf{p} \otimes \mathbf{p} \otimes \mathbf{p} \otimes \mathbf{p}\, \psi(\mathrm{p})\, d\omega$$

(Tucker 1987)

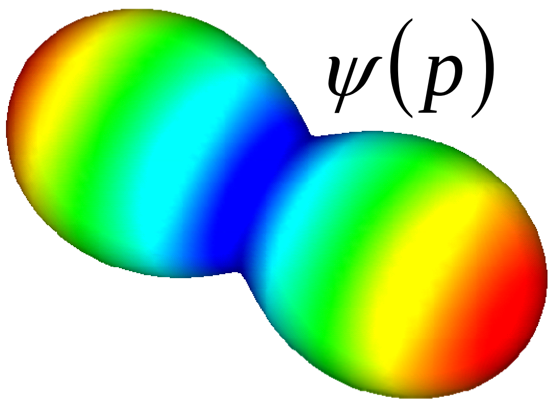




Taylor expansion of ODF

$$\psi(\mathbf{p}) = \frac{1}{4\pi} + \frac{15}{8\pi} + dev(\mathbf{a}) : dev(\mathbf{p} \otimes \mathbf{p})$$

$$+ \frac{315}{32\pi} dev(\mathbf{a}^4) :: dev(\mathbf{p} \otimes \mathbf{p} \otimes \mathbf{p} \otimes \mathbf{p}) + \ldots$$

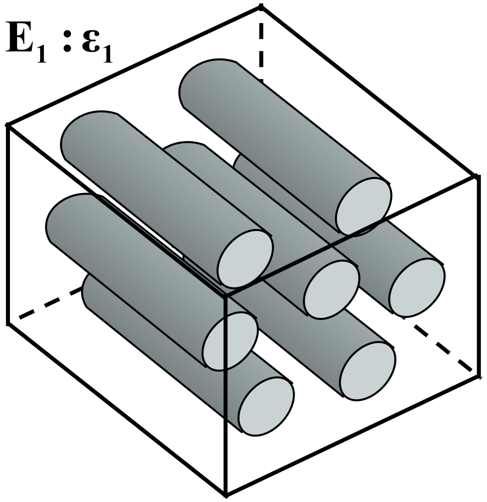


Homogenization of fibers and polymer

Mean Field Theory (Mori and Tanaka,Tandon and Weng)

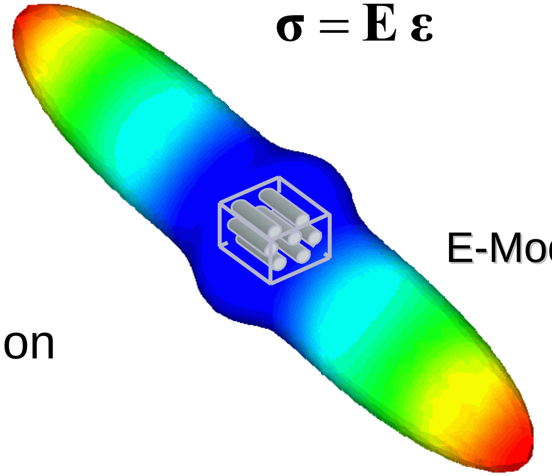
$$\boldsymbol{\sigma}_0 = \mathbf{E}_0 : \boldsymbol{\varepsilon}_0$$

$$\boldsymbol{\sigma}_1 = \mathbf{E}_1 : \boldsymbol{\varepsilon}_1$$



Homogenization

$$\overline{\boldsymbol{\sigma}} = \overline{\mathbf{E}}\,\overline{\boldsymbol{\varepsilon}}$$



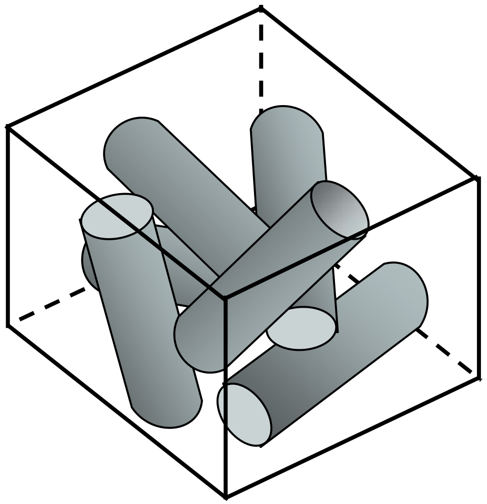
$$\overline{\mathbf{E}} = \left[c_1\mathbf{E}_1 : \mathbf{B}^{\varepsilon} + (1-c_1)\mathbf{E}_0\right] : \left[c_1\mathbf{B}^{\varepsilon} + (1-c_1)\mathbf{I}\right]^{-1}$$

$$\mathbf{B}^{\varepsilon} = \left(\mathbf{I} + \mathcal{E}_{(\mathbf{I},\boldsymbol{\omega})} : \left[\mathbf{E}_0^{-1} : \mathbf{E}_1 - \mathbf{I}\right]\right)^{-1}$$

$\mathcal{E}_{(\mathbf{I},\boldsymbol{\omega})}$ **: Eshelby Tensor**

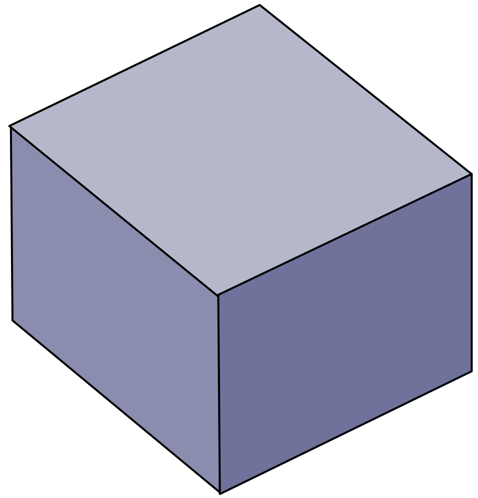
Material modelling for composite materials

Micro Scale



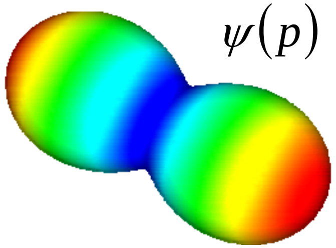
Homogenization:

Macro Scale

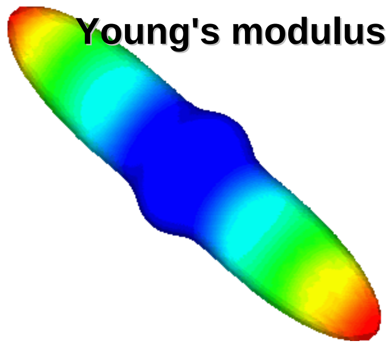


Orientation distribution function

$\psi(p)$



Young's modulus



Integrative Simulation ULTRASIM™

Data flow structure

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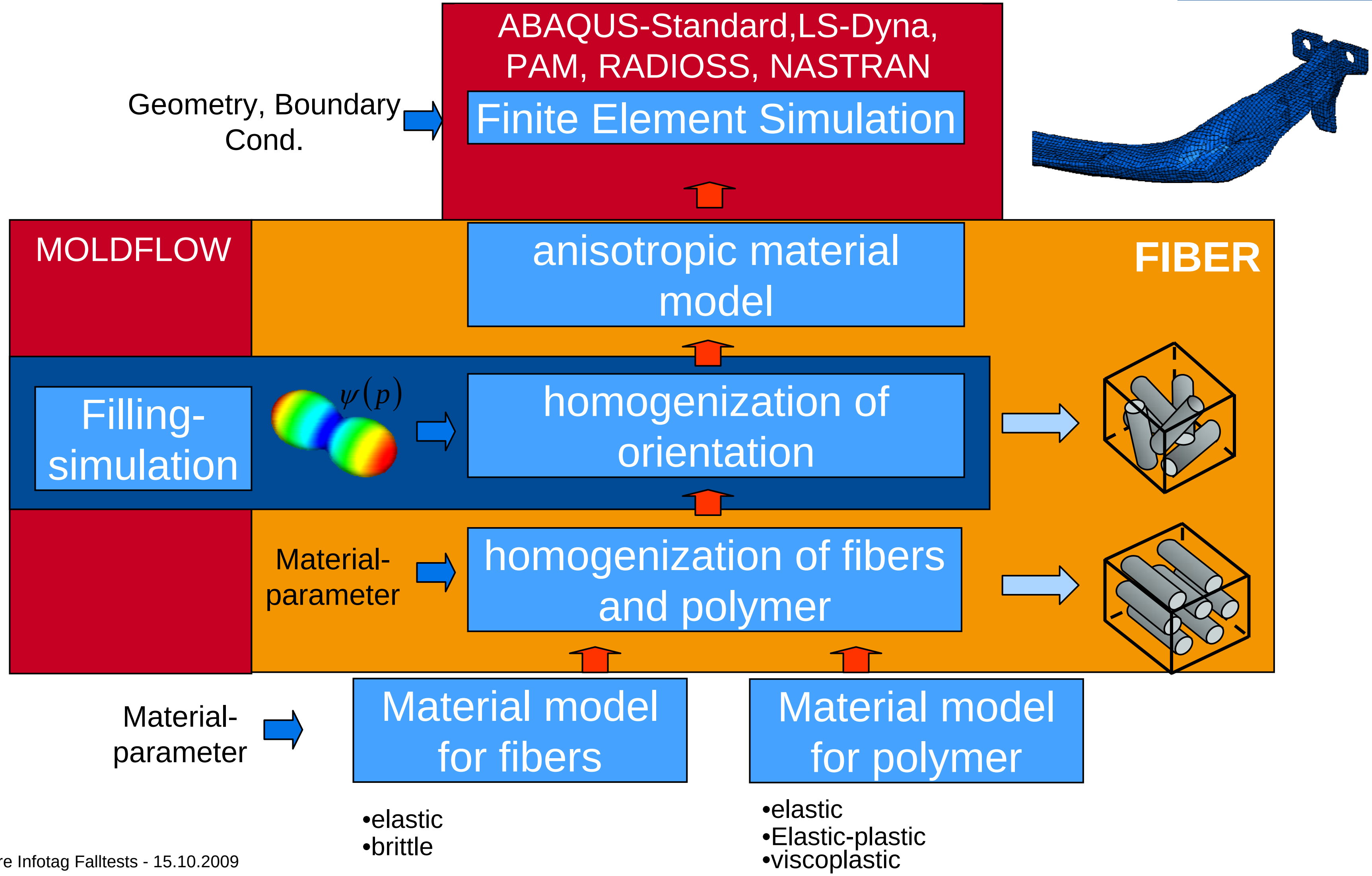
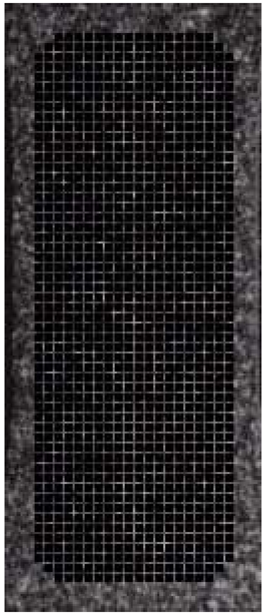


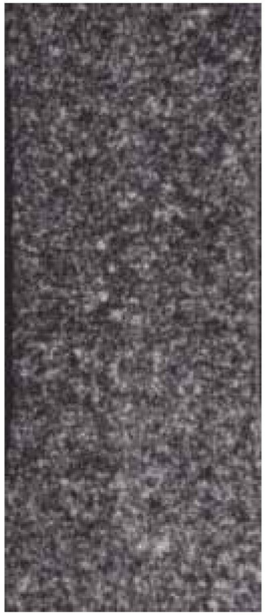
Material Measurements

Data Flow

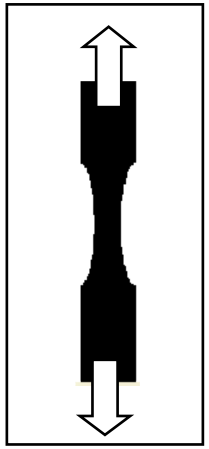


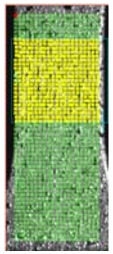
GOM - ARAMIS

Deformation Gradient $\mathbf{F} = \frac{\partial \mathbf{x}}{\partial \mathbf{X}}$



$Force(t)$

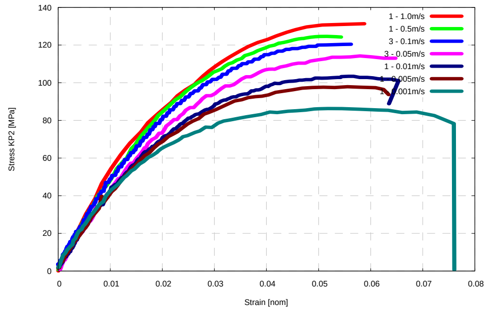




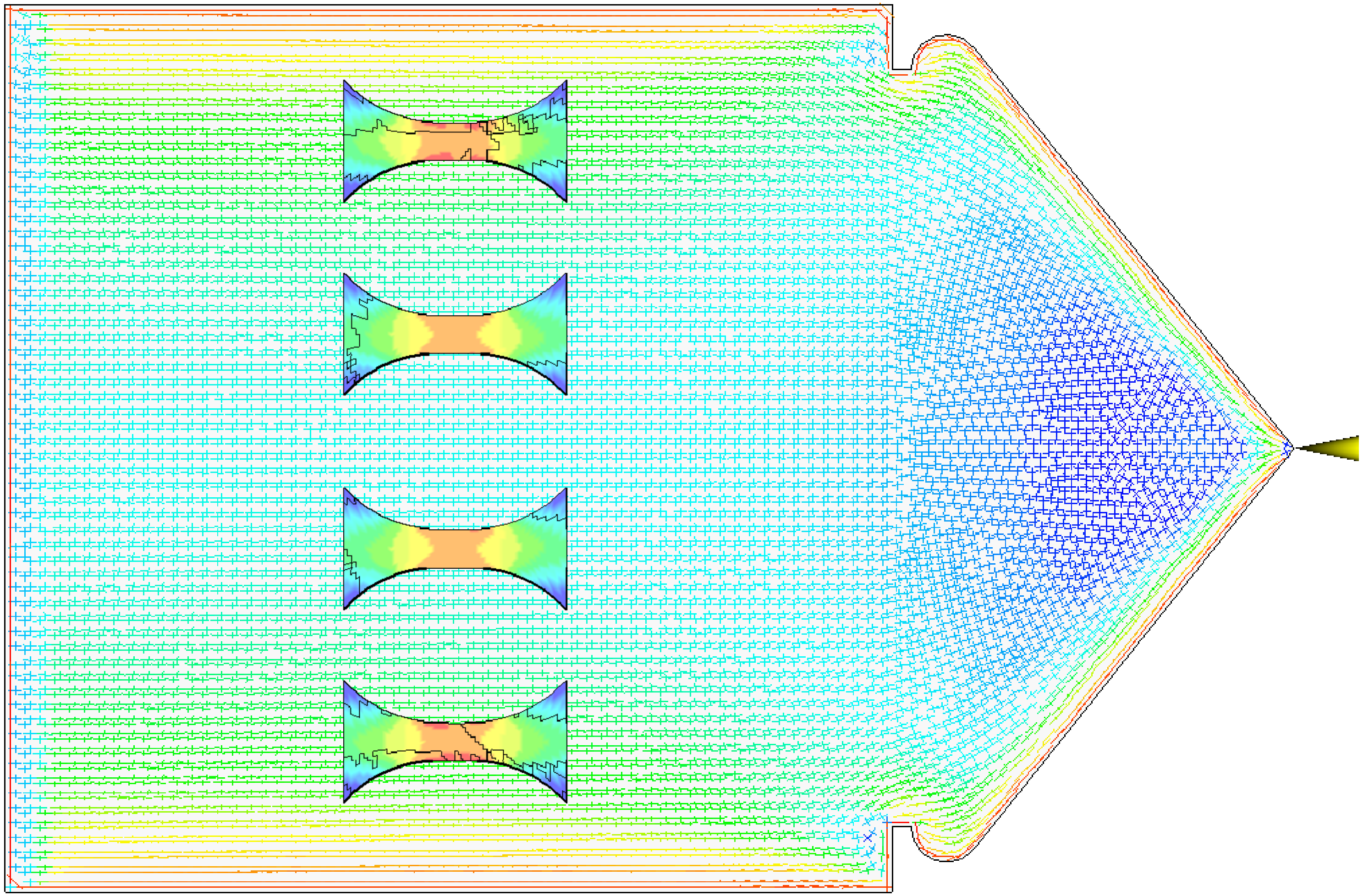
BASF Software

$\mathbf{F} = \frac{\partial \mathbf{x}}{\partial \mathbf{X}} \longrightarrow$ Strain: $\mathbf{E} = \frac{1}{2}(\mathbf{F}^{\mathrm{T}}\mathbf{F} - \mathbf{G})$, $\mathbf{e} = \frac{1}{2}(\mathbf{g} - \mathbf{F}^{-\mathrm{T}}\mathbf{F}^{-1})$

$S^{11} = \frac{Force(t)}{A_0}$ Stress: $\boldsymbol{\sigma} = \frac{1}{J}\mathbf{FSF}^{T}$



Average Fiber orientation and Failure variable



Failure variable

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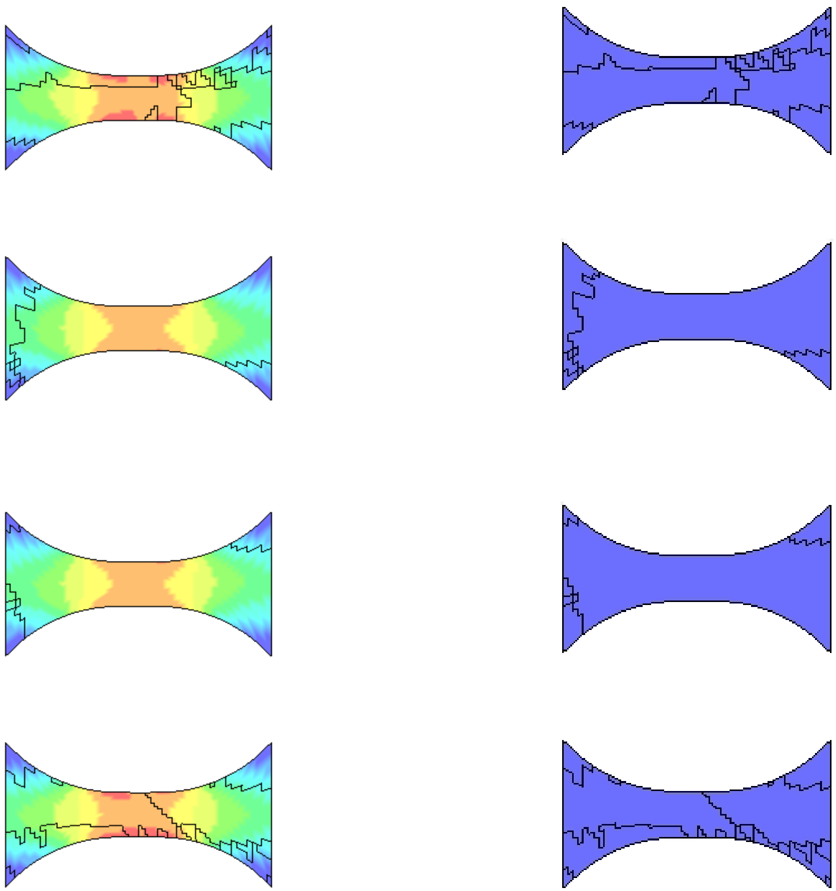

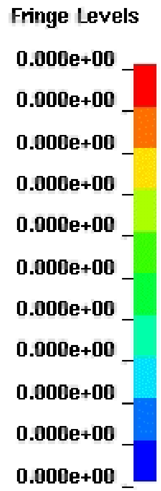

Penetration Experiment

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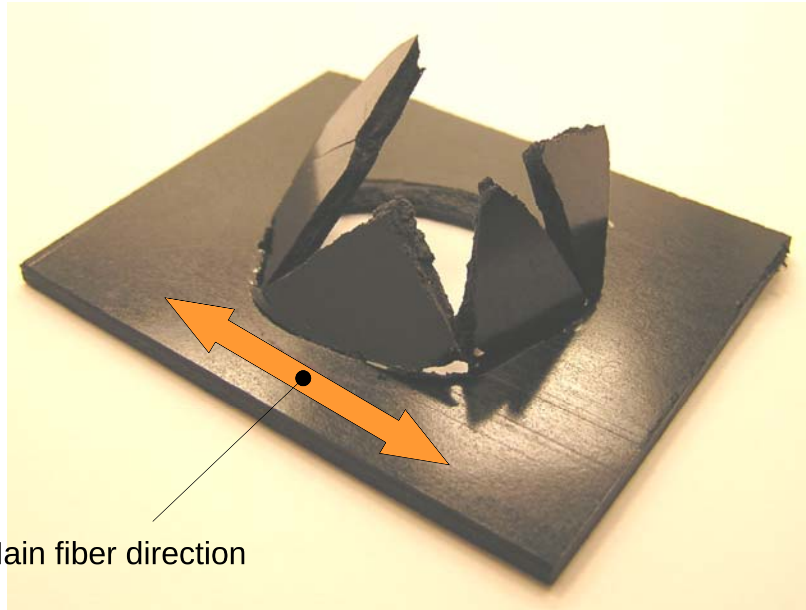
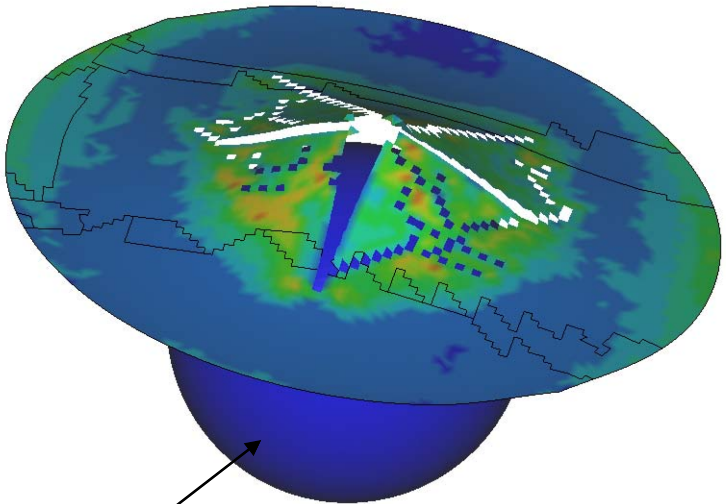


Biaxial Stress



Simulation of penetration experiment

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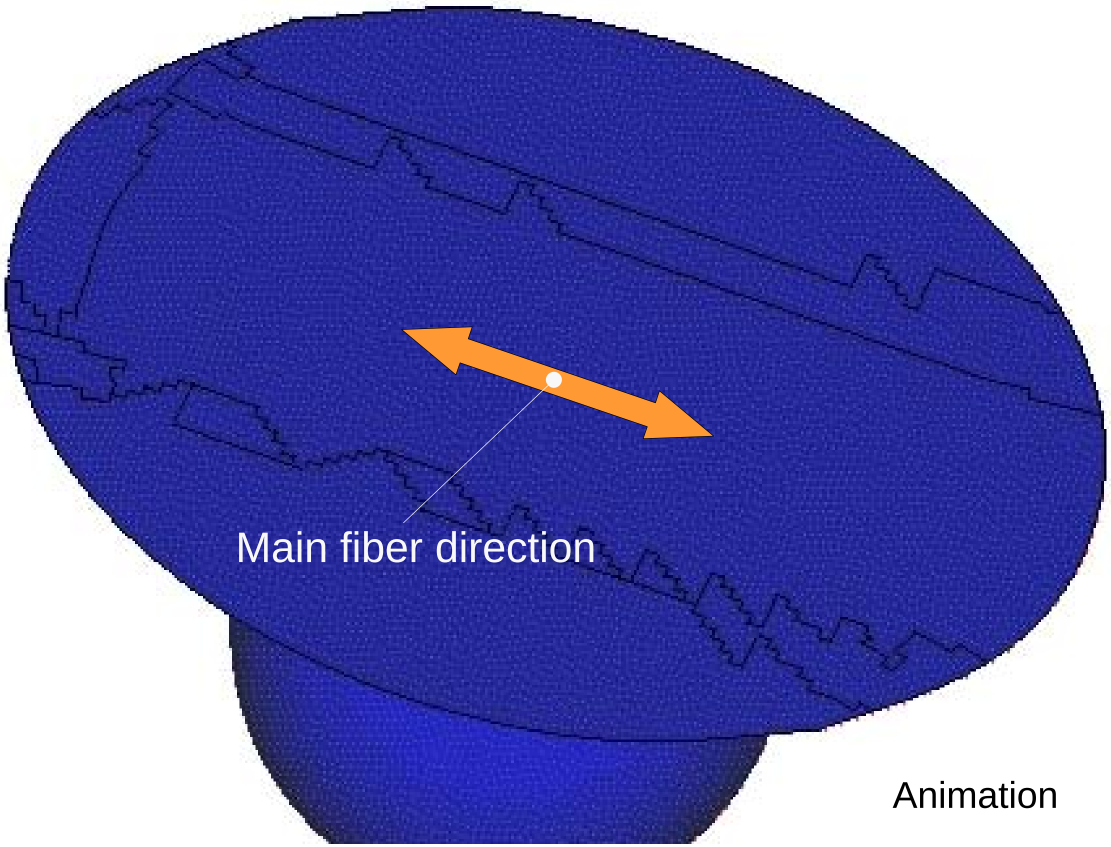
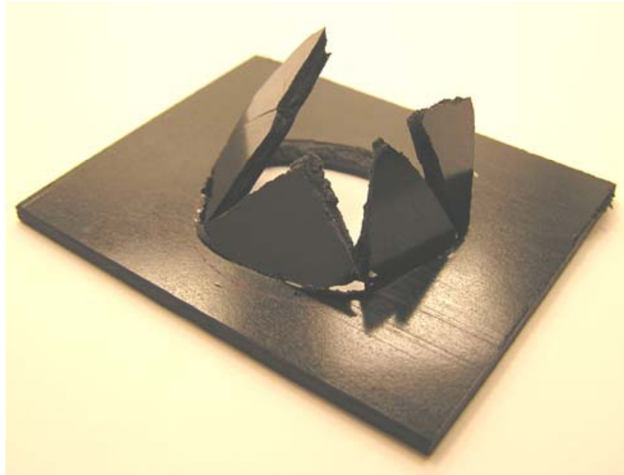
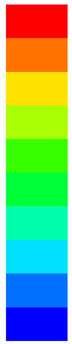


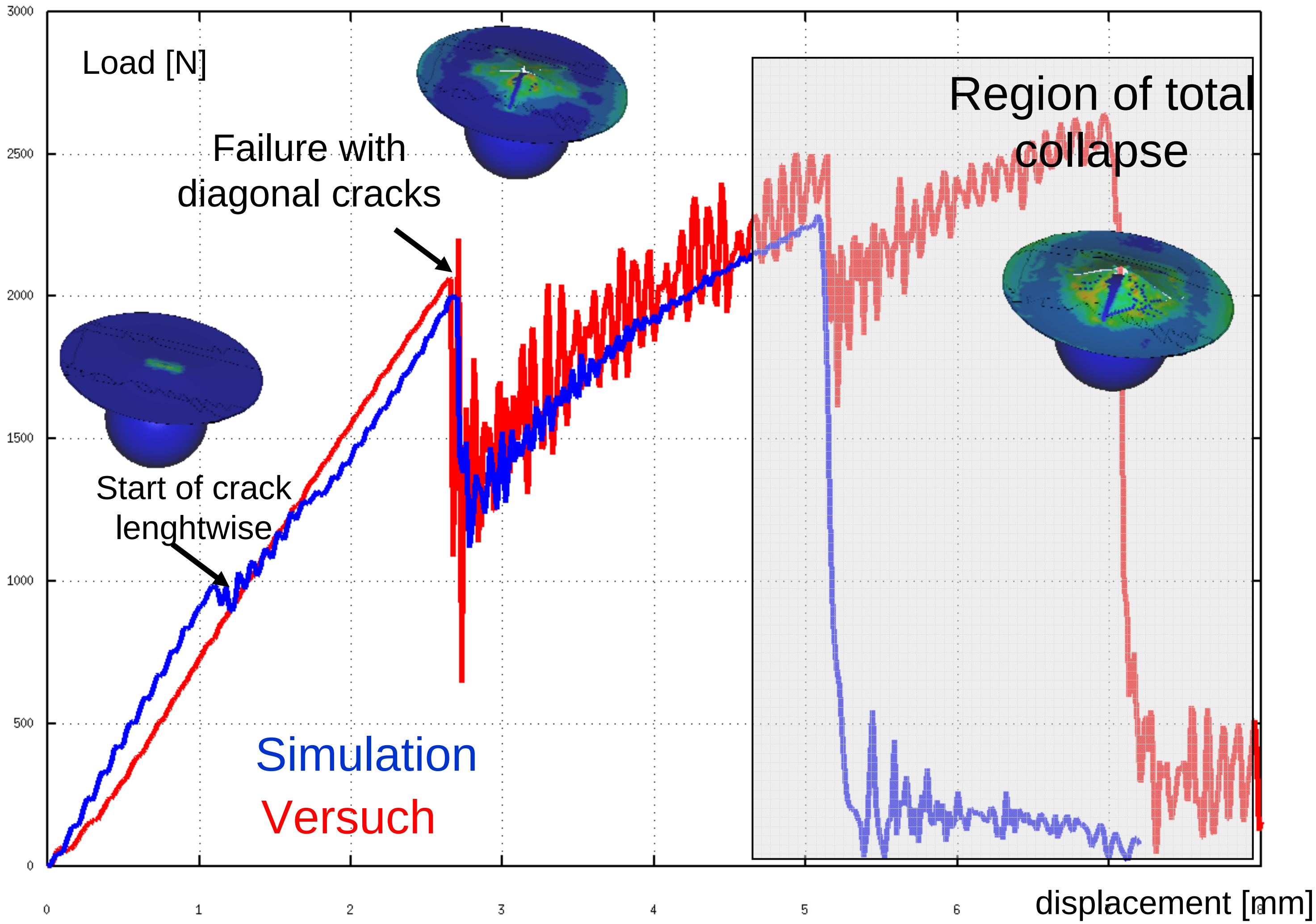
Animation





Loading

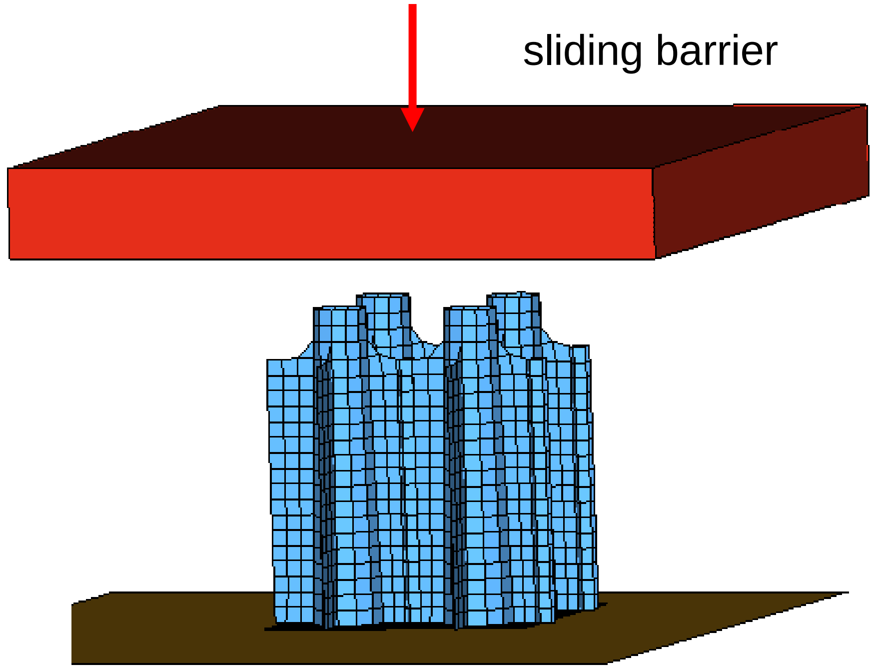
Simulation of penetration experiment



Test Specimen for compression load

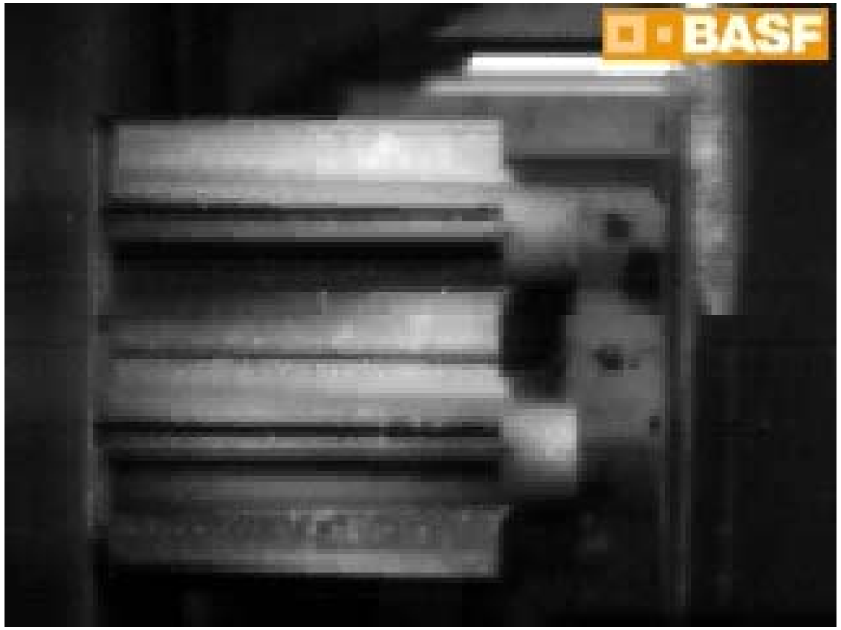
Specimen is designed for controlled collapse

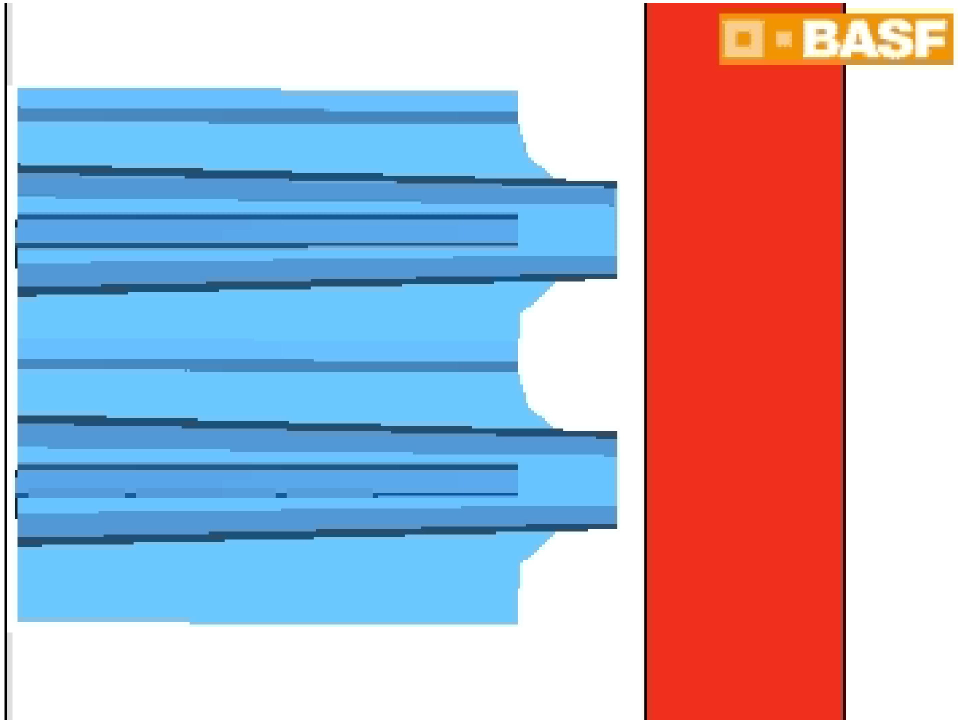
Material: B3WG6 CR (PA6 GF30%)



Plastic specimen under compression load

Simulation and Experiment

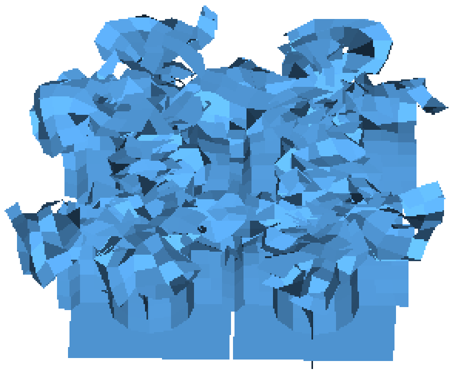


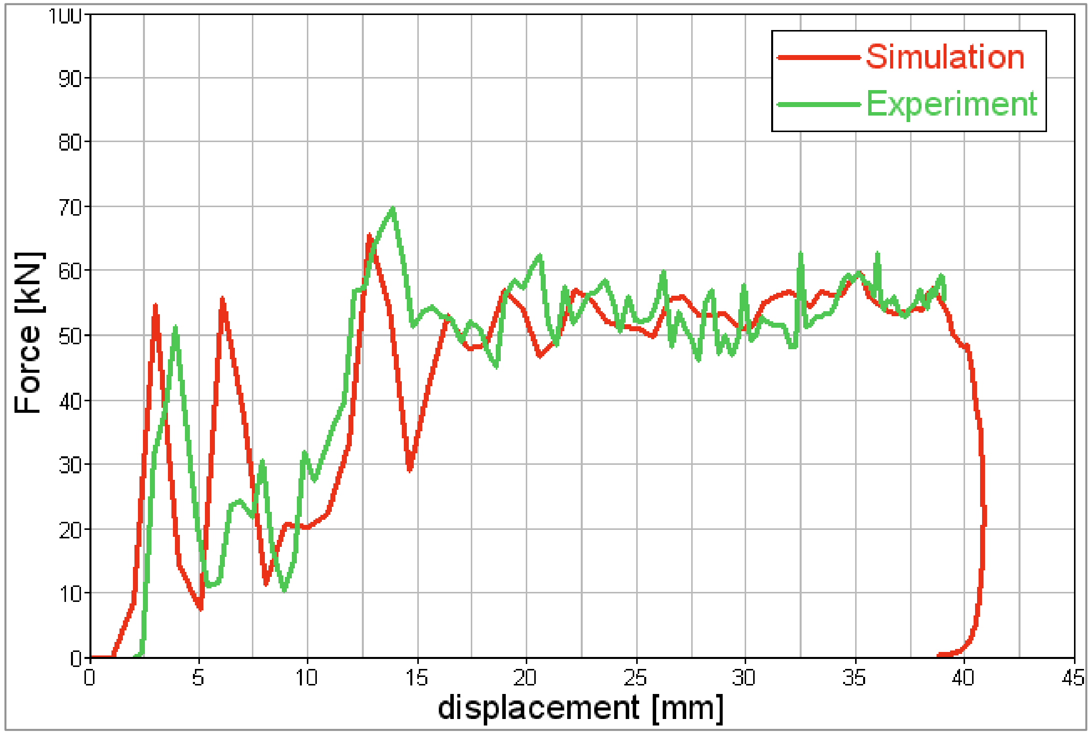


Test-specimen under compression load

Simulation and Experiment

60 mm



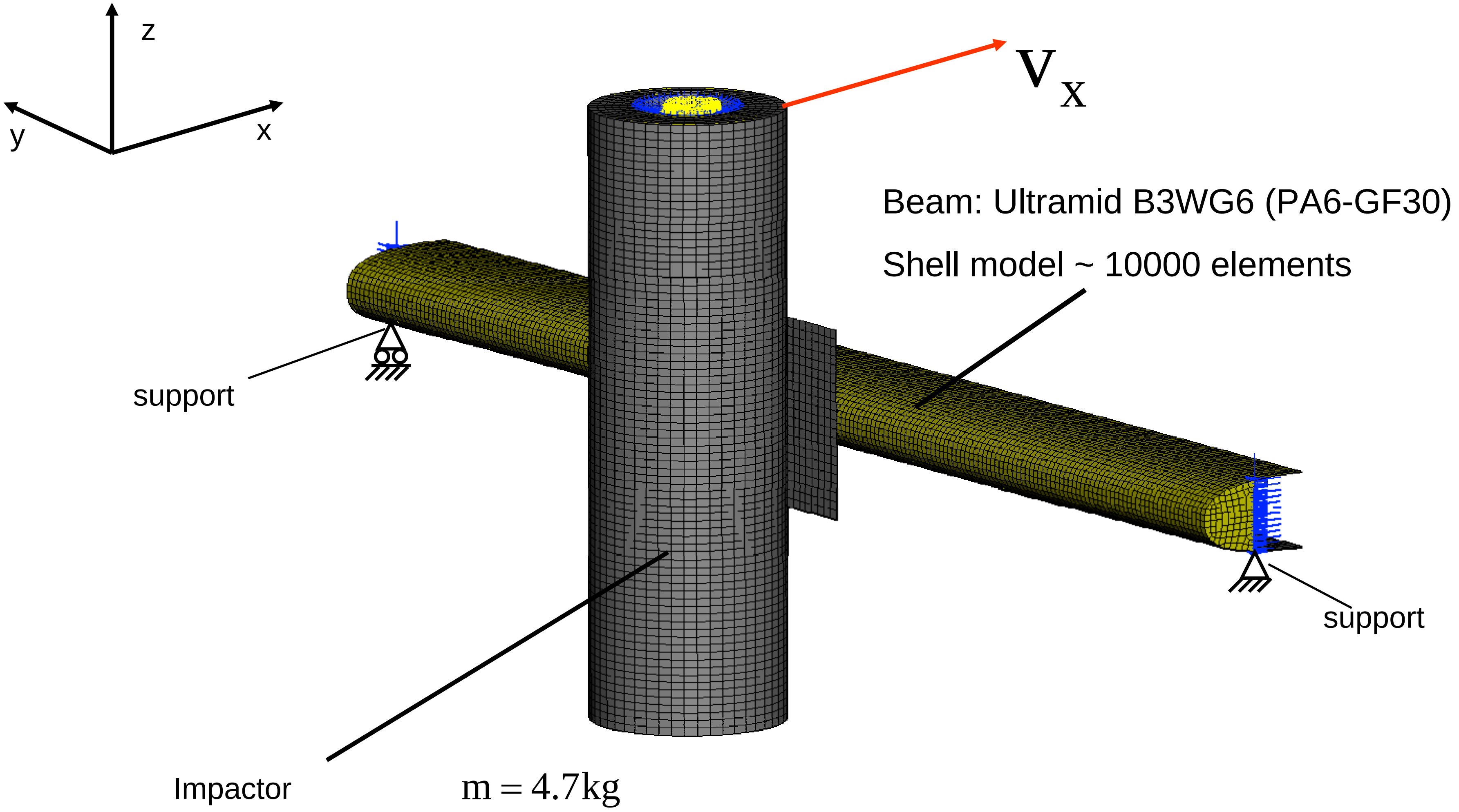


Illustrated Example

Importance of Fiber Orientation

Mechanical test set-up

Lower leg shot on supported beam



Illustrated Example

Importance of Fiber Orientation

Filling pattern and fiber orientation
Filling calculation with MOLDFLOW

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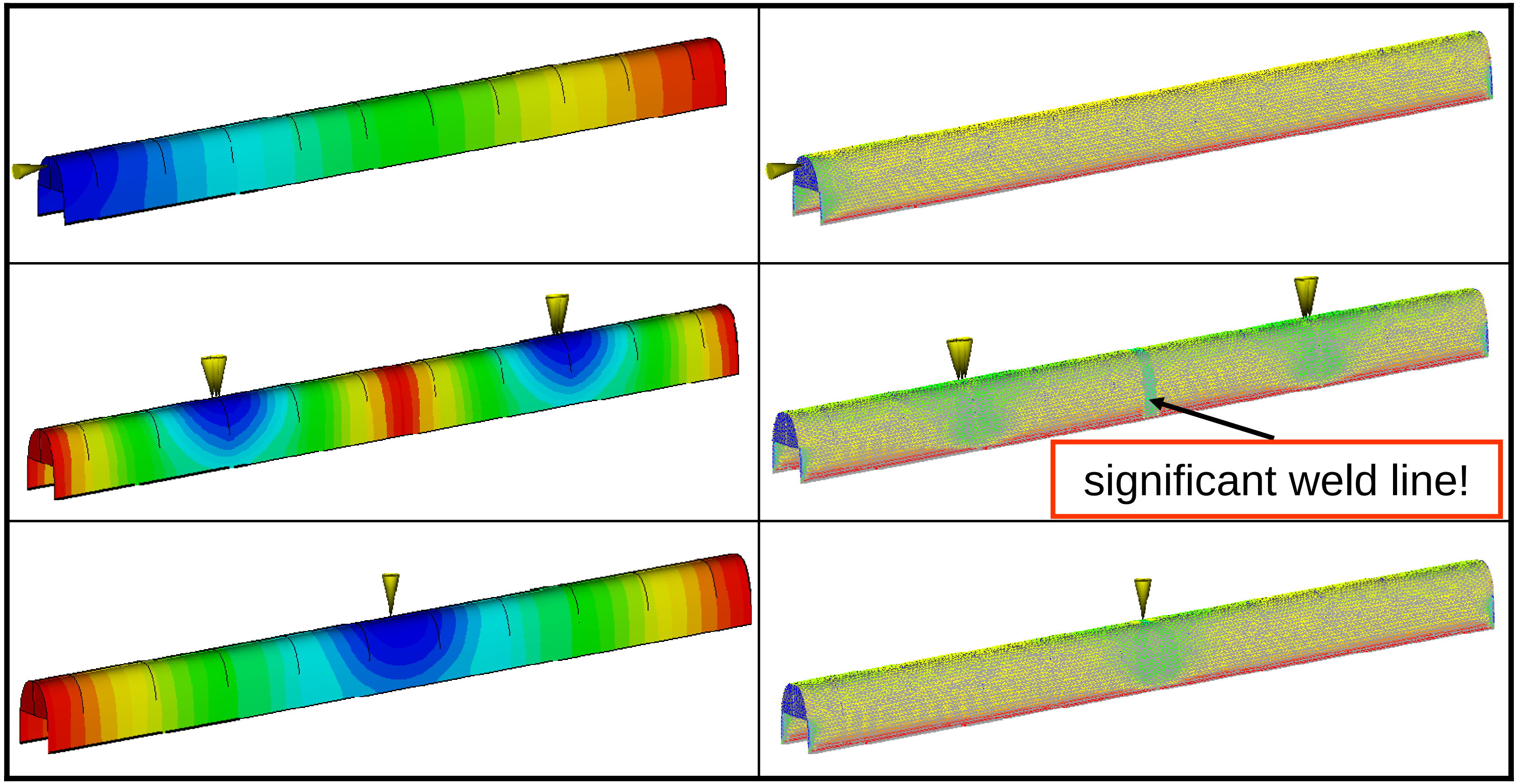
Filling pattern | Fiber orientation

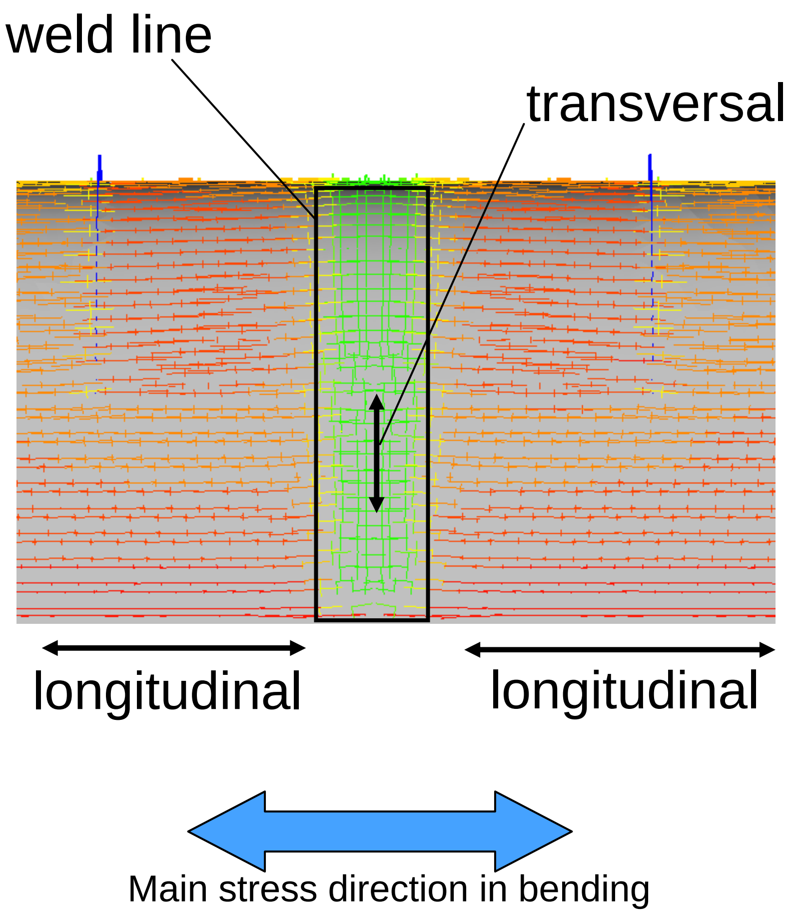
Case A

Case B

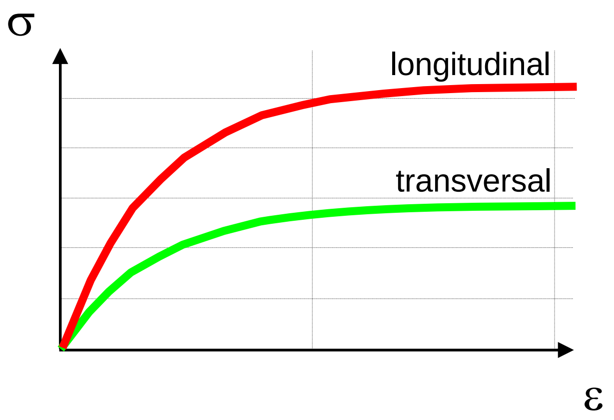
Case C

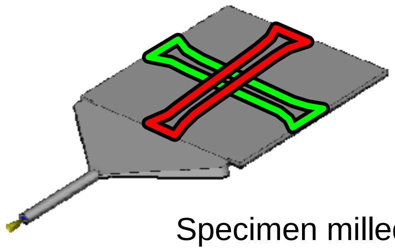


Detail of fiber orientation in weld line
Case B



σ-ε diagram





Specimen milled out of injection molded plate

Illustrated Example

Importance of Fiber Orientation

Results with v=11.2 m/s

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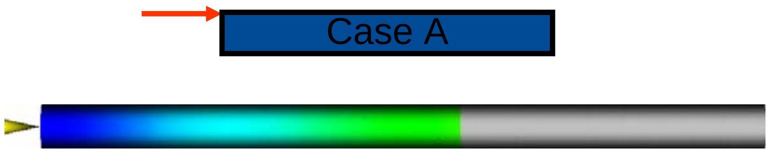
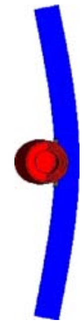
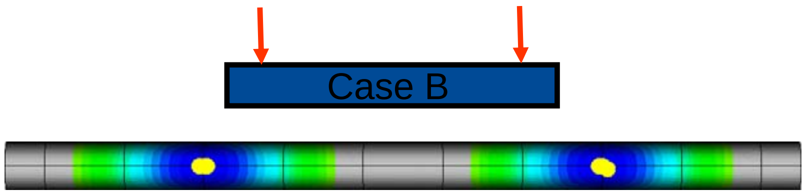
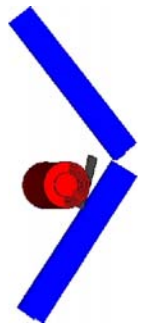
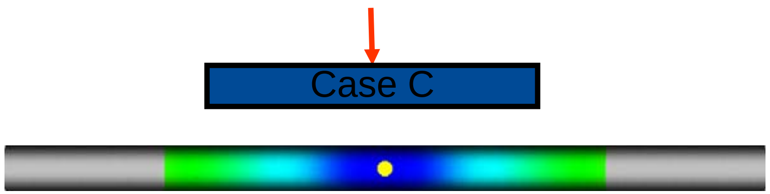
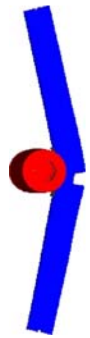
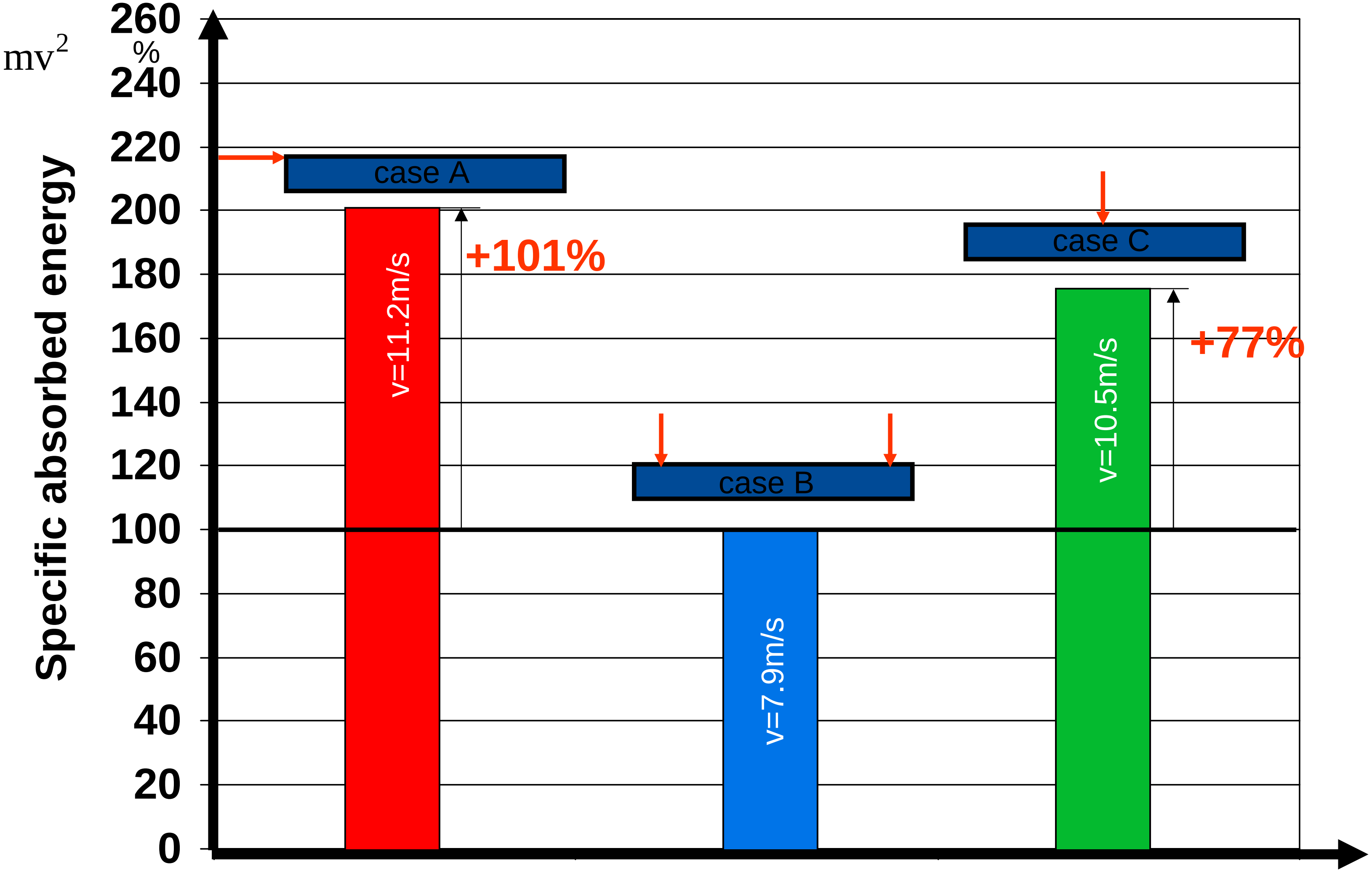
 Case A: Part without failure!	
 Case B: Failure!	
 Case C: Failure!	

Illustrated Example

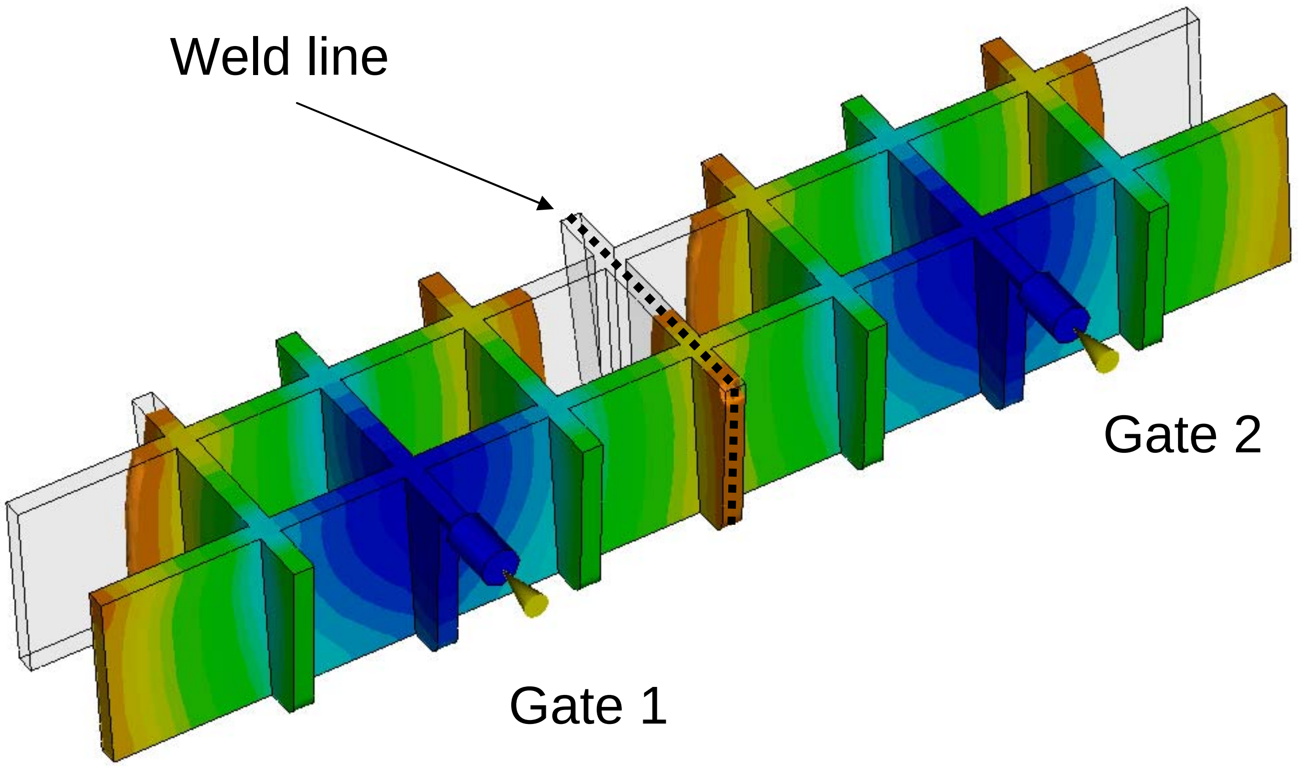
Importance of Fiber Orientation

Comparison of absorbed energy

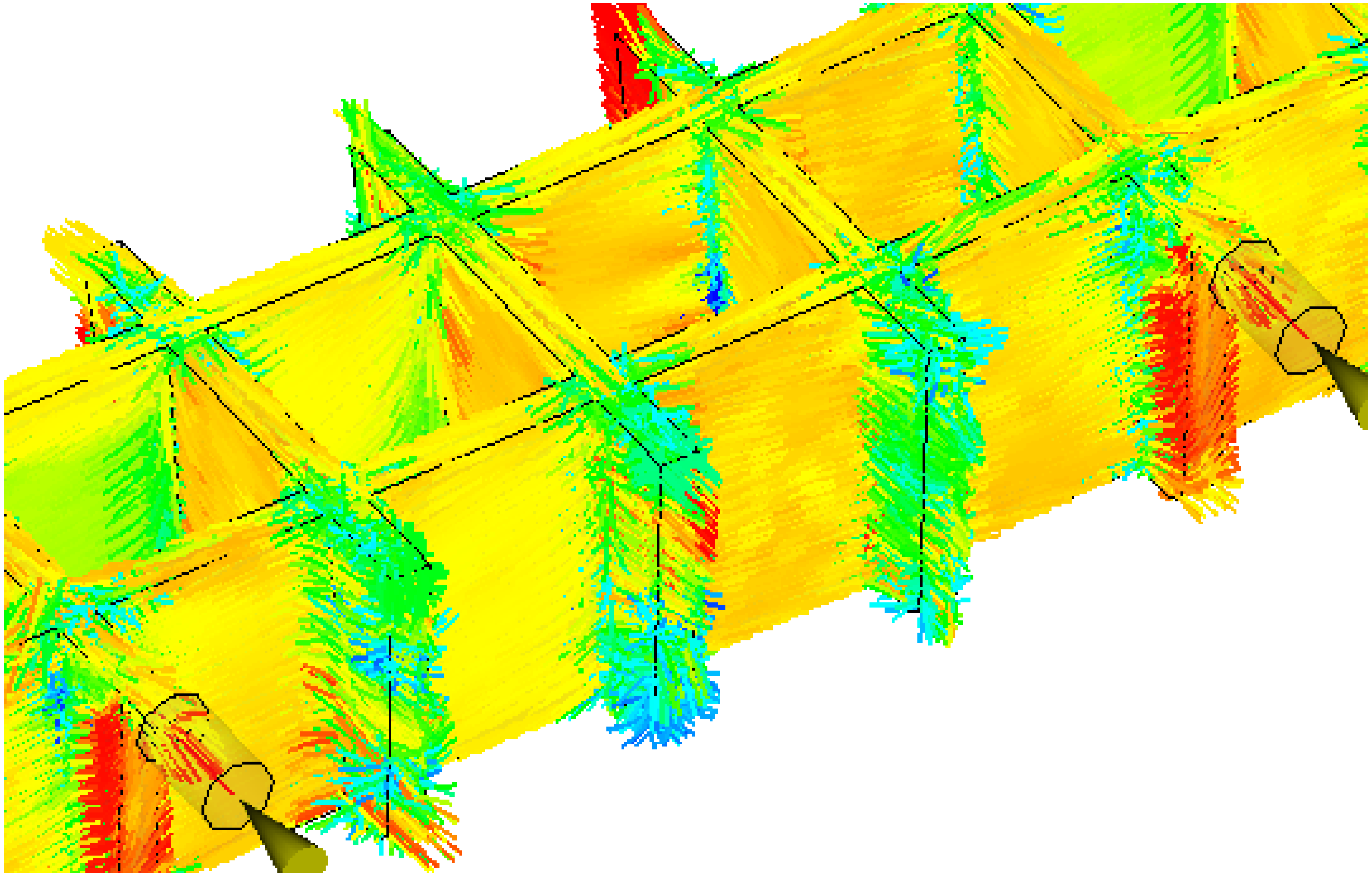
$$E = \frac{1}{2} m v^2$$



Filling pattern and weld line



Fiber orientation



Failure in weld line - symmetric bending

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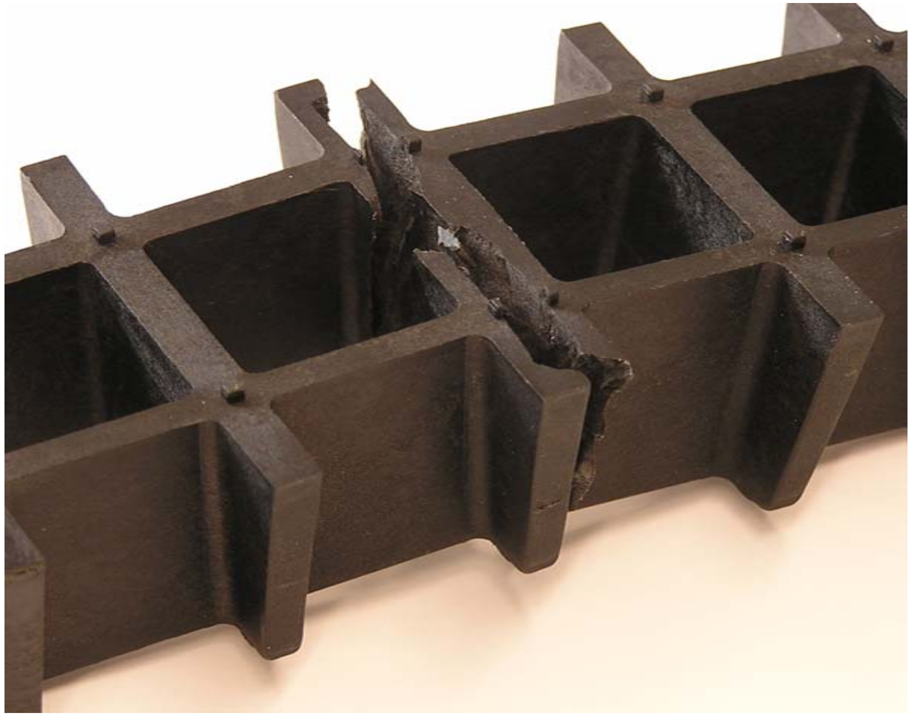
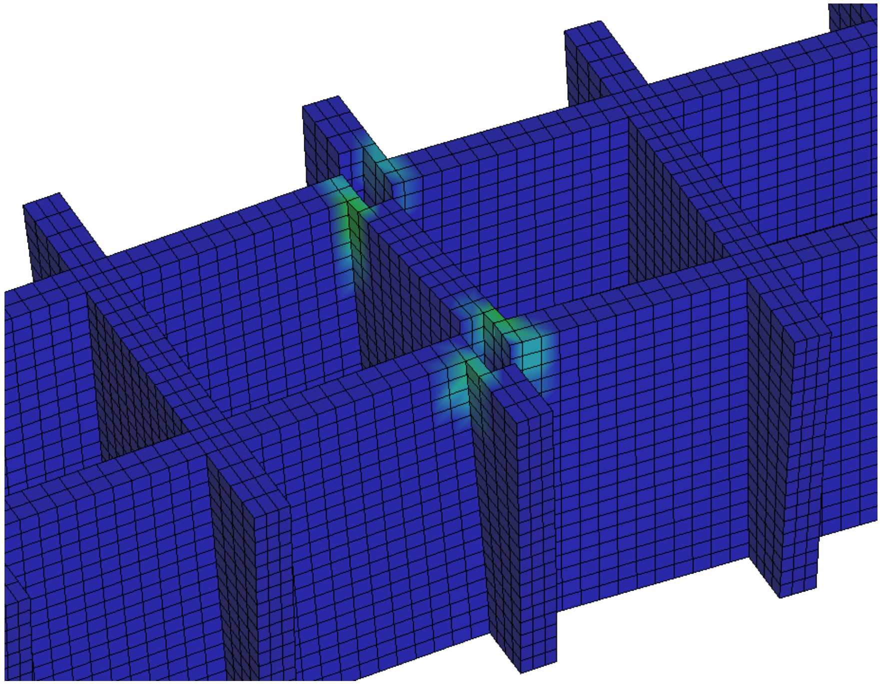


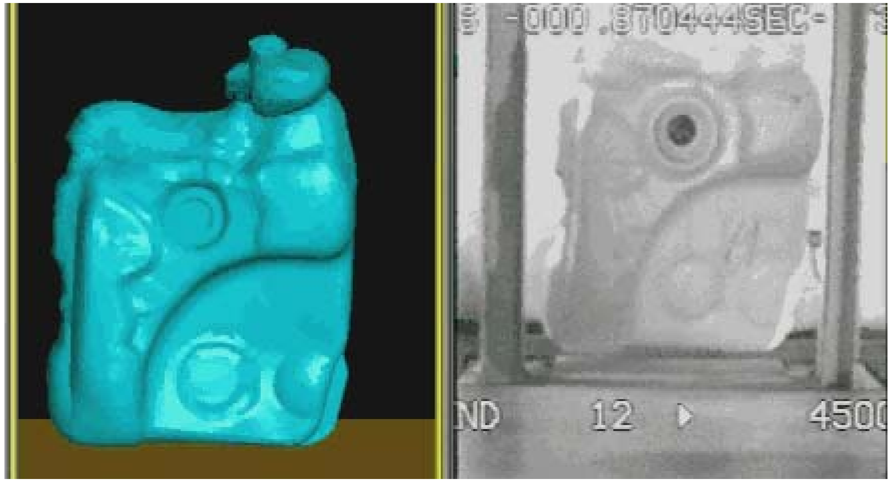


Zusammenfassung

- Simulation von Falltests stellt neue Herausforderungen
  - Kinematik → Kontakt
  - Abbildung von Verbindungen → Beispiel Schraube
  - Materialverhalten → ULTRASIM
  - Versagen → ULTRASIM
- Materialmodellierung mit BASF ULTRASIM™
- Bindenahteinfluss bei faserverstärkten Kunststoffen
- Beispiele

Vielen Dank für Ihre Aufmerksamkeit!

Einfluss der Materialmodellierung von thermoplastischen Kunststoffen auf Ergebnisse von numerischen Falltests



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